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EFFECT OF ROTOR DESIGNS ON THE ACCURACY OF THE PRICE METER

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EFFECT OF ROTOR DESIGNS ON THE ACCURACY OF THE PRICE METER

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ABSTRACT

Three plastic rotor designs, including the Water Survey of Canada plastic design, and the standard metal rotor used in Price current meters were assessed for their abilities to estimate flow velocity. The effects of vertical and sideways velocity components on the relative error of their velocity measurement were examined for all rotors.

Results indicate that: (i) the standard metal rotor is more accurate than all the tested plastic rotors; (ii) the upper pivot of both the standard cat whisker head and the fibre optic assembly are improperly designed for flow situations where vertical velocity components are encountered; and (iii) modification of the meter to incorporate fibre optic pick-ups will probably lead to significant decreases in accuracy over that obtained for the conventional cat whisker head.

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The data documented in this report stem from ongoing equipment testing. Without the leadership and hard work of Mr. Klaus Wiebe of the Hydrometric Methods Section, Water Survey of Canada and Mr. Peter Engel of the Environmental Hydraulics Section, National Water Research Institute, these data would not have been available. Their reports and several discussions with them have provided the impetus for this comparative report.

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1. INTRODUCTION

The Water Survey of Canada (WSC) is part of the Water Resources Branch of the Inland Waters Directorate, Environment Canada. The main function of WSC is to collect water quantity data on a national basis (Campbell and McBride 1990). In order to estimate the discharge of a given stream or river, reliable estimates of velocity are required.

The Price Current Meter is the most commonly used device, in North America, to measure stream velocities. The meter consists of six conical, hollow cups mounted on a rotor that rotates about the vertical axis (Figure 1). The rotor has traditionally been constructed of brass with a nickel or chrome plating used for protection (Engel et al. 1986). The Price meters currently being used are individually calibrated for the WSC by the National Water Research Institute (NWRI) at their laboratory in Burlington.

Recently, rotors that are constructed of plastic have attracted interest because of their potentially lower purchase cost (Engel et al. 1986), as compared to metal rotors, and the possibility of conducting batch calibrations rather than individual calibrations. Batch calibration offers the advantages of reducing costs, as well as enabling field technicians to change damaged rotors without having to return the meter for recalibration.

NWRI has conducted studies to uncover the sampling characteristics of three plastic rotors of different design. Each of these rotors (Figure 2) have cups that vary in shape from the metal rotor that

is currently being used by the WSC. One of the plastic rotors tested is a design that, prior to NWRI testing, was adopted by the United States Geological Survey (USGS). The purpose of the testing program was to try to improve on the USGS design before going ahead with production of a WSC type plastic rotor (Engel et al. 1986).

This report analyzes performance data that have been collected by NWRI for both metal rotors and the three different plastic rotors. The analyses compares how each meter responds when placed in each of the three following flow situations:

1. normal to the flow in both the horizontal and vertical plane;

2. at varying departures of vertical alignment away from the horizontal plane; and

3. at varying departures of horizontal alignment away from the vertical plane.

The effects of vertical and horizontal departures, as listed above under items 2 and 3, are used to simulate the effects of vertical and sideways velocity components acting on the rotor. These velocity components can be encountered in field situations where the flow is not parallel to the channel. Engel and DeZeeuw (1978 and 1979) have shown that Price meters are subject to errors in estimating velocity when placed in either of these situations. The purpose of this report, then, is to compare the various plastic rotor designs with the standard metal rotor and determine which

rotor is the most accurate (for all situations tested) and/or the most predictable in its behaviour. The WSC standard method of applying a cosine correction to sideways velocities is also examined.

This report also suggests and discusses design improvements that may enhance the performance of plastic rotors.

2. ROTOR RESPONSE THEORY

Engel et al. (1986) describe the mechanics of rotor response. Their theoretical model development will be described herein as it is fundamentally important for understanding the response characteristics of the Price Meter.

The equation of motion for a rotor can be described using Newton's Second Law for Rotational Motion. This law states that the summation of the torques acting on a system equals the moment of inertia of the system multiplied by its angular acceleration (Ogata 1978). This can be shown as (Engel et al. 1986)

$$T_1 - T_2 - T_f = I\,(dw/dt) \qquad (1)$$

where T_1 = the torque exerted on the rotor in the direction of meter rotation

T_2 = the torque exerted on the rotor in the direction opposite of meter rotation

T_f = the torque exerted on the rotor by friction in the

direction opposite of meter rotation

I = the moment of inertia of the rotor

$I = mk^2$

m = mass of rotor

k = radius of gyration of the rotor

w = angular velocity of the rotor

The torques T_1 and T_2 are caused by the drag forces of water acting on the cups, multiplied by the radius of the rotor. Forces due to drag can be described by the general equation (Mott 1979)

$$F = (1/2)pC_DAv^2 \qquad (2)$$

where F = force due to drag

p = density of water

C_D = drag coefficient

A = area

v = velocity

Equation (2) is only an approximation of the actual drag forces acting on rotor. The magnitudes of both the area and drag coefficients are continually changing as the rotor turns.

Because the cups are rotating, the velocity term in equation (2) has to be adjusted by the linear velocity, wr, of the rotating cups. The torque caused by the drag is then the product of the drag force multiplied by the radius, r, of the rotor. The corresponding drag torques now become

$$T_1 = (1/2)\rho C_{D1} A (v - wr)^2 r \quad (3)$$

$$T_2 = (1/2)\rho C_{D2} A (v + wr)^2 r \quad (4)$$

Equation (1) can be rewritten in the form

$$I\,(dw/dt) + bw = T_1 - T_2 \quad (5)$$

where $bw = T_f$

b = friction constant

The left side of equation (5) describes the motion of the rotor, while the right side is the forcing function that causes the rotor to turn.

Two assumptions are implicitly used in equation (5). The first is that the static and dynamic friction constants are the same and are combined additively to form the b term. The second assumption is that the forcing function, $T_1 - T_2$, is a step input. A step input is instantly applied at a magnitude that remains constant over time. This is not completely true because the actual velocity acting on the meter is a function of the angular velocity, w, as described in equations (3) and (4). In reality the forcing function is a slight ramp input. For the metal meter, wr is approximately 27% of v regardless of velocity v. This allows the terms (v - wr) and (v + wr), to be rewritten as (v - 0.27v) and (v + 0.27v) respectively. Similar percentages of wr with respect to v could be calculated for the other rotors. This assumption eliminates the w and w^2 terms that are in T_1 and T_2, allowing for a

much easier solution of equation (5).

The solution of equation (5), with the initial conditions of w = 0 and (dw/dt) = 0 at time t = 0, is

$$w(t) = \frac{T_1 - T_2}{b} (1 - e^{(-b/I)t}) \qquad (6)$$

Equation (6) describes the angular velocity w of the rotor at any time, t, after the meter is placed in the stream.

3. CONCEPTS IN MEASUREMENT

There are three fundamental concepts (Figure 3) that must be considered when examining experimental data: bias, precision (repeatability), and accuracy. Bias is the difference between the mean of a sample taken from a given population and the mean of the population itself. Precision describes the ability of a measurement to repeat the same value every time the measurement is conducted. Precision is often represented mathematically as the mean squared error (MSE), the root of which is referred to as the root mean squared error (RMSE) or standard deviation of the sample members about their sample mean. Errors attributed to precision are usually considered to be random (Kennedy and Neville 1986), while bias may be of a systematic nature. Accuracy is a function of bias and precision and represents the closeness of a measured value to the true value. Accuracy can be described as:

$$\text{Accuracy} = (\text{Bias}^2 + \text{Precision})^{1/2} \qquad (7)$$

Figure 3 illustrates accuracy, bias, and precision. A is more accurate as the data are unbiased and have low RMSE. The results are reasonably repeatable and precise. B are inaccurate as the data are highly biased. Their RMSE is low hence results are repeatable and precise. If you could correct for bias, then the data of B would be represented by A and would become "accurate". C are inaccurate as the data are not precise, they have a high RMSE. They are, however, unbiased.

If bias is systematic and is deterministic, then observations may be adjusted. This would have the effect in equation (7) of setting the bias to zero. Hence, the accuracy measure would decrease (improve) and remain a function of precision. Consider the example of weighing an object with a known mass, say 10 kgs, on a new scale. If the scale indicates 12 kgs every time the object is placed on the scale, the scale would have a high degree of precision, but is not terribly accurate. The inaccuracy is the result of a bias described as a systematic error. The scale could be recalibrated to remove the bias. If this were done, the scale would then be considered accurate. Using the same example, say the scale indicated masses varying greatly but with a mean of 10 kgs. The bias tends to zero as there is no systematic error. The variance of the measurements represents the precision of the sampling, and in this case represents the accuracy.

It can be seen that a high degree of accuracy is very desirable for any measuring device.

4. CONCEPT OF COSINE CORRECTION

4.1 Field Situation

Velocity measurements are required in order to estimate the discharge of a stream or river. The measurement section is divided into "n" panels, where the WSC standard is a minimum of twenty panels. Velocity measurements are taken within each panel. The discharge of a panel, Q_i, is $\overline{V_i} * A_i$. A_i is the cross sectional area of the panel. $\overline{V_i}$ is the mean velocity of the panel that is in the downstream or x direction. Figure 4 illustrates the coordinate system, where $V_i = V_x$. Velocities in the y and z directions, V_y and V_z respectively, also exist in natural streams because of turbulent flow and irregular channel geometry. V_y is a vertical velocity, and V_z is a sideways velocity. However, only the velocity in the x direction, V_x, is used when computing discharge. The total discharge of the river, Q_t, is $\sum_{i=1}^{n} Q_i$.

Velocity measurements are often conducted with the meter attached to a handheld wading rod. For simplicity, a two-dimensional case with no V_z component will be used as an example. The technician holds the rod so that the meter rotor is parallel to the streambed and water surface, and therefore lying in the V_x plane. For a handheld wading rod assembly, V_x can be described as acting planar to the rotor. However, where the meter is positioned, the V_x plane often does not correspond to the plane through which the water is flowing. The actual flow may be through the V_s plane. The actual velocity vector, V_s, can be resolved into a horizontal component, V_x, and a vertical component, V_y. V_x is the velocity at which water

is moving downstream and is the velocity that should be used for the discharge calculation. Mathematically, $V_x = V_s * \cos \Theta_y$, where Θ_y is the angle between V_x and V_s. Theoretically, the ideal meter would always indicate V_x, the cosine of the V_s velocity, regardless of the angle. Practically, this is not possible because of the limitations of meter and/or rotor design. The question, then, is how accurately does the standard metal rotor meter, or any of the plastic rotor meters, provide V_x when Θ_y is not zero.

4.2 Laboratory Set-Up

Some of the tow tank experiments conducted by NWRI simulate flows that are not planar to the rotor. That is, the meter is held at an angle Θ_y to the V_s plane with no V_z component. A schematic of the tow tank velocities is shown in Figure 5. The meter is towed at the velocity V_s. The velocity acting on the plane of the rotor is still V_x. Note that in the laboratory, velocities have been rotated by an angle Θ_y in comparison with the field situation. V_x remains equal to $Vs * \cos \Theta_y$. Towing the meter in this manner simulates the effects that vertical velocity components, V_y, have on the behaviour of the rotor.

It is crucial to relate the velocity vectors of the laboratory testing with those of field conditions. In both situations, we want the meter to accurately measure V_x, not V_s. **The meter's ability to measure V_x is of interest as V_x should be the velocity vector used to compute the channel's discharge.** Thus far, NWRI have reported the meter's ability to measure Vs, rather than V_x, for different angles of Θ_y and Θ_z, for their tow tank data.

4.3 Discussion

It is critical that the effects of vertical and sideways velocity components on rotor behaviour be known. In field conditions, it is difficult, if not possible, to determine the angles of these components. The ability of the rotor to measure V_x may depend on V_x, and θ_y and θ_z. Laboratory testing can provide insite on how accurate the meter is under various conditions.

If a meter would measure V_x with the same accuracy regardless of angle it could be described as being "cosine correcting". Such a meter would always measure V_x. The V_y and V_z components of the flow would not affect the behaviour of the rotor. In reality, the Price meter's rotor is affected by the presence of V_y and V_z components. This effect may be somewhat related to the cosine of θ_y and θ_z. In order to examine any possible relation, let $\hat{V}_x$ be the V_x velocity indicated by the meter. The relative error in the meter's estimation of the actual downstream velocity, V_x, is then RE (%). Mathematically, $RE\ (\%) = [(\hat{V}_x - V_x)/V_x] * 100$.

In order to determine a correction factor that can compensate for the RE (%), a relation between the relative error and its causative factors must be known. RE (%) is some function of V_s, V_y, V_z, θ_y, and θ_z. As we do not measure θ_y presently in the field, it is important to assess its effect on the relative measurement error of V_x.

5. EXPERIMENTAL DATA

The data presented in this report were interpolated from graphical results of experiments conducted by NWRI (Engel and DeZeeuw 1978 and 1979; Engel et al. 1986), as data in tabular form were not available. The graphical results adopted are for one metal rotor, identification number 1-179, and three plastic rotors, labelled P-1, P-3, and P-4. Figure 2 shows the various shapes of these plastic rotors.

NWRI tested the meters in a concrete towing tank filled with water. The dimensions of the tank are 122 m by 5 m with a water elevation of 2.7 m (Engel and DeZeeuw 1978). The meters were attached to a towing carriage that travels on rails. As the carriage moves at a predetermined velocity, a computer calculates the actual velocity of the carriage, V_s, and hence the meter, and counts the number of revolutions that the meter rotor makes per second, N.

To evaluate the performance of a meter at a given velocity, the N value is divided by the velocity, V_s, at which it was towed. The N/V_s ratio is the number of revolutions that the rotor turned per meter distance towed through the water, where the velocity is measured in meters per second. The N/V_s ratio indicates how much the rotor "slips" in the water. At low velocities, when the rotor has just begun to turn, the rotor "slips" in the water more that when it is towed at high velocities, and therefore has lower N/V_s values at low velocities. Plots of N/V_s versus V_s are used to show how the meter is behaving at different velocities. Note that a rotor having no "slip" would have a N/V_s ratio of approximately

4.24. It was from these plots in the three aforementioned reports that the data used in this report were extracted. An explanation of the data and methods used in this report, and contained in the appendices, is in Appendix A. The extracted data are listed in Appendix B.

As was indicated earlier, the intent of this report was to evaluate the various rotors abilities to measure the actual downstream velocity V_x given that there may be vertical or sideways velocity components acting on the rotor. It has already been indicated that the velocity data collected by NWRI are V_s data, not V_x data. Meter estimations, $\hat{V}_x$, of the actual planar (or downstream) velocity, V_x, have been generated from the NWRI data. The methods used to generate these data are described in Appendices A and C.

The data from the three reports, and therefore the data used in this report, are the result of single trial testing. This means that only one trial was conducted for a given meter towed at a particular velocity and position. Therefore no estimate can be assigned to the precision or repeatability of any of the measured data. This implies that the accuracy of a meter to measure a particular velocity, while positioned in the flow a certain way, is determined using a N/V_s value that may or may not be close to the mean N/V_s value that would result if several trials were made. Without repeated trials, the ability to distinguish between errors of bias or precision is very limited.

6. RESULTS OF ANALYSIS

6.1 Meter Placed Normal to Flow

This situation has the meters placed in complete alignment with the flow in both the horizontal and vertical planes. The data for each of the meters have been plotted and are shown in Figure 6. These data are listed in Appendix D. The metal rotor, 1-179, has the largest N/V_s ratios, and therefore the least amount of slip, at all the velocities tested. Rotor P-1 has the smallest N/V_s values up to a velocity of 0.35 m/s after which it has only slightly larger values than rotor P-3.

Comparing 1-179 and P-1 shows the effects of a hollow cup versus a solid cup, both with conical frontsides. The differences in mass (Table 1) between these two rotors can be neglected since the rotors are in steady state rotation. P-1 has a much lighter weight in water compared to 1-179 (43% of 1-179's weight), however, the difference in friction generated on the lower pivot due to the difference in weight is most likely insignificant compared to the large differences in the backside drag coefficients. 1-179 has N/V_s values that are approximately 10% larger at all velocities. The shape of the curve for P-1 is very similar to that of 1-179, indicating the characteristic effect that the conical frontside has on rotor behaviour.

P-1 and P-3 both have a solid cup, but have different frontside shapes. P-1 has a conical front, while P-3 has an elliptical front. The meters differ in mass, and their weights differ in

water slightly. The amount of friction loss due to a weight change is probably insignificant as explained in the previous paragraph. P-3 has slightly larger N/V_s values for velocities less than 0.35 m/s. Above 0.35 m/s, P-1 has values that are slightly larger than the values for P-3. The N/V_s values are within about 6% of one another regardless of velocity. The data indicate that the more rounded frontside shape of P-3 reduces rotor slippage more significantly at lower velocities.

P-4 has the same frontside shape as P-3, but has a slightly hollowed out backside. The hollowing causes more drag on the backside of P-4 as compared to P-3, and the data indicate that less slippage (larger N/V_s values) is occurring at all velocities for P-4, especially at velocities less than 0.40 m/s. P-4 has N/V_s values that are about 5% larger for velocities less than 0.25 m/s and 3% larger for higher velocities. The shape of the curves for these two rotors are again similar to each other indicating the effect on rotor behaviour due to the elliptical front.

The completely hollowed back of 1-179 results in the rotor with the least amount of slippage at all velocities. The rotors with the elliptical frontsides reach an approximate steady state N/V_s value at velocities lower than the rotors with conical frontsides (approximately 0.20 m/s compared to 0.50 m/s).

6.2 Meter Placed with Vertical Departure

This situation has the meters placed with various departures in vertical alignment, both above and below the horizontal plane that is parallel to the flow (Figure 7). This laboratory set-up is used to simulate field conditions where velocity fields are not acting planar to the rotor. Angles of departure used were 5, 10, and 15 degrees above (+) and below (-) the horizontal plane. For a given meter at a particular angle of departure, the percent relative error, RE (%), was calculated for the velocities 0.10, 0.25, 0.50, 0.75 and 1.00 m/s. The RE (%) is the difference between the meter's estimation of the downstream velocity and the actual downstream velocity, divided by the actual downstream velocity. This can be expressed mathematically as

$$RE\ (\%) = [(\hat{V}_x - V_x)/V_x] * 100$$

This calculation was repeated for all angles of departure. The RE (%) illustrates the effects that vertical velocity components, V_y, have on the meter's ability to measure the actual downstream velocity, V_x. Negative RE (%) values indicate that the meter would underestimate the actual downstream velocity. Positive RE (%) values indicate an overestimation of the actual downstream velocity. The data for each of the rotors have been plotted in Figures 8 to 11. These data are listed in Appendix E.

In theory, if a meter's rotor and yoke assembly were constructed so that it was perfectly symmetrical in shape and internal design, and if the flow fields around the meter were exactly the same

regardless of whether the meter was tilted above or below the horizontal plane, then the RE (%) values should be symmetrical about the zero degree vertical departure point shown in Figures 8 to 11. Simply put, the RE (%) for a given angle above the horizontal plane should equal the RE (%) for the same angle below the horizontal plane. Figures 8 to 11 show that all of the meters have larger RE (%) values for angles above the horizontal plane than for the same angles below the horizontal plane, regardless of velocity. This is most likely a function of the design of the yoke assembly and not the rotor itself, although the rotor design and/or material may exaggerate the effect. When the meter is tilted above the horizontal plane, vertical velocity components are: (i) lifting the rotor off the highly machined lower pivot, and (ii) pushing the rotor shaft up into the bottom of the chamber cap. Although the top of the rotor shaft is rounded, it provides more friction than that generated by the bottom pivot of the meter when it is aligned with the flow. In effect, the friction coefficient, b, in equation (6) is significantly increased resulting in a smaller angular velocity, w, and hence a smaller N/V_s value, for the same approximate difference in drag torques. The plastic rotors may be affected more than the metal rotor because their submerged weight is less than one half of the metal rotor's submerged weight. This makes them more susceptible to the effects of vertical velocity components.

A simple test was performed to illustrate the differences in friction between the top and the bottom pivot points of the rotor shaft. The standard Spin Test was performed on a metal rotor meter (1-049). It spun for over three minutes. The meter was then

inverted (Inverted Spin Test) and spun a second time. The rotor spun for only forty seconds before coming to an abrupt halt. Another metal rotor meter fitted with an optical head (1-228) spun for only 10 seconds when inverted. The Inverted Spin Test roughly approximates the drag forces exerted on the meter when vertical velocity vectors are present.

Due to the inadequate design of the Price meter with regards to upward vertical velocities, no comparisons will be made concerning angles above the horizontal plane. Comparisons will only be made concerning angles below the horizontal plane. This is assuming that the downward velocity components will have insignificant effects on the friction coefficient, b, of the bottom pivot.

Differences between the left of zero portions of Figure 8 (1-179) and Figure 9 (P-1) are due primarily to rotor shape. The former is a hollow cup while the latter is a solid cup. Both rotors have conical frontsides. For 1-179 the RE (%) values vary in magnitude over a range from about -1.8% to 1.9%, regardless of angle of vertical departure. Effects on the magnitude of RE (%) due to velocity appear to be random. The RE (%) values for P-1 appear dependant on velocity. The RE (%) ranges in magnitude from +5.7% to -2.7% at an angle of five degrees to a range of -3.7% to -13.4% for an angle of fifteen degrees. The scatter shown in Figure 9 illustrates the sensitivity of the solid cup to changes in velocity. P-1 also shows unpredictable behaviour at low velocities. Its RE (%) curve for 0.10 m/s does not have the same smooth shape as do the other rotor's curves.

P-1 and P-3 both have solid cups. P-1 has a conical front, while P-3 has an elliptical front. P-3 has a narrower range of RE (%) values, randomly distributed across an approximate 2% range for the different velocities for all of the angles as compared to P-1 (Figure 10). The RE (%) values are also smaller in magnitude for P-3, by about one-half, than they are for P-1. These results indicate that the elliptical front is less sensitive to downward velocity components.

P-4 has a slightly hollowed backside, and the same frontside shape as P-3. P-4 has the smallest RE (%) values for most velocities and angles of the plastic rotors including P-1 (Figure 11). The difference is most notable at ten degrees where the range in RE (%) for P-3 is -2% to -3% as compared to the range of 0% to -2% for P-4, and -3% to -7% for P-1. The slight hollowing of P-4 causes the % RE values for ten degrees to become more akin to values for 1-179, which has a conical front and a completely hollowed back.

In general, all rotors underestimate V_x for the majority of conditions. The completely hollowed back of meter 1-179 results in a rotor that is less affected by vertical velocity components as compared with the other rotors. The decrease in RE (%) as a result of a slight hollowing of the P-3 design confirms this theory. As well, rounding of the front of P-3 improves its performance over P-1, as it is made less sensitive to velocity and angle of alignment. These points suggest that the rotor that may be affected the least by vertical velocity components would be a rotor with an elliptical frontside and an completely hollowed backside.

6.3 Meter Placed with Horizontal Departure

This situation has the meters placed with various departures in horizontal alignment, both to the left (-) and right (+) of the vertical plane (Figure 12). This laboratory set-up is used to simulate field conditions where velocity fields are flowing sideways into the rotor. Angles of departure used were 10, 15, and 30 degrees on both the left and right sides. The RE (%) values were calculated in the same manner and at the same velocities as in the vertical departure case. The data for each of the rotors have been plotted in Figures 13 to 16. These data are listed in Appendix F.

When the meter is placed such that it has a horizontal departure from the vertical plane the flow field around the entire meter changes compared to the flow field that surrounds a meter aligned with the flow. This is the result of the position of the yoke behind the rotor. The yoke, because it is turned, now has a relatively large frontal area that acts as an obstruction disrupting the flow. The disruption's effects on the rotation of the rotor are not symmetric about the completely aligned meter position. This is a result of the disruption's effects of the altered velocities on the different drag torques for the frontside and backside of the cups.

The data for the metal rotor meter are a combination of the results of two meters; meter 1-179 was used for the 15 and 30 degree angles and meter 1-061 was used for the 10 degree angles. For simplicity, the data for the two meters will only be referred to as 1-179.

1-179 (Figure 13) and P-1 (Figure 14) both have conical frontsides, but 1-179 has a completely hollow cup, while P-1 has a solid cup. The RE (%) values for 1-179 appear to be slightly dependent on velocity. For most angles, this dependency had a range of about 2% for velocities of 0.10 to 1.00 m/s. The range in values is larger for plus and minus 10 degrees than other angles (7% in the left direction and 3% in the right direction). The data for the 10 degree to the right position contain some points that appear suspicious. Interestingly, the 10 degree departures for P-1 also show a marked increase in their scatter as compared with the other angles. It is difficult to ascertain if the RE (%) values for the 10 degree departure are representative of the actual situation. Repeated trials during testing would resolve the situation.

The RE (%) values for P-1, for all angles, appear to be somewhat dependent on velocity. This dependency ranges from 4 to 12% and is related to the horizontal departure angle. RE (%) results for the 0.10 m/s velocity appear erratic. Except for the 0.10 m/s velocity, 1-179 and P-1 have RE (%) values that are similar in magnitude for all angles and velocities. 1-179 is less sensitive to changes in velocity, especially when the meter is turned to the right.

P-1 and P-3 both have solid cups, but P-3 has an elliptical front. The RE (%) of P-3 (Figure 15) is also dependant on velocity for the angles tested. The conical frontside of P-1 is more erratic for low velocities (0.10 m/s) than the elliptically shaped rotor. If the 0.10 m/s line is excluded from P-1, P-1 has smaller RE (%) values for most velocities and angles as compared to P-3. In

particular, P-1 has RE (%) values that are about 4% smaller than the P-3 values for all velocities when the angle is 30 degrees to the right. For an angle of 30 degrees to the left, the P-1 values are about 2% smaller. However, the RE (%) results of the P-3 rotor are more stable and predictable than P-1 results for all angles.

P-4 and P-3 both have elliptical fronts, but P-4 has a slightly hollowed back. P-4's behaviour is also dependant on velocity. P-4 gives similar results (Figure 16) to P-3 for both magnitude and range of RE (%) values for most angles with the exception of 30 degrees to the right. Here, P-4 is clearly superior to P-3.

In general, all rotors will measure V_x within approximately 5% for angles between about 20 degrees to the left and 20 degrees to the right. The differences in the RE (%) values for the various rotors within this region is comparatively small. All rotors overestimate V_x for the majority of conditions. Low velocities, 0.10 m/s, tend to give RE (%) values that do not follow the "family" of curves that the other velocities produce. This is particularly true for 1-179 and P-1. This indicates that the conical front is more unpredictable in its low velocity behaviour as compared to the elliptical front rotors. For angles greater than 20 degrees to the left and right, 1-179 is clearly superior to the other meters in estimating V_x should the angle of horizontal departure not be known. Note that the RE (%) of P-3 are the most predictable provided that the angle is known.

Standard WSC field procedures call for the application of a cosine correction to the measured velocity if the angle θ_z can be

estimated. The next section investigates the effect that the cosine correction has on the magnitude of the relative error in the meter's estimation of V_x.

6.4 Effects of Horizontal Cosine Corrections

The concept of applying a cosine correction to sideways velocity fields is based on the assumption that the rotor is estimating V_s, and not V_x, even though V_x is the desired velocity. For simplicity, the velocity that the meter indicates will still be called V_x; a more proper name may be V_s. In theory, multiplying the velocity value that the meter gives by the cosine of the angle of flow, θ_z, should give the actual downstream velocity V_x. However, the yoke of the meter disrupts the flow fields surrounding the meter and, therefore, the meter is not measuring V_s completely accurately. This, in turn, results in an error in the estimation of V_x. This section investigates the error in the V_x estimation when a cosine correction is applied.

The data used for this analysis are the same data used in the previous section. However, the meter's estimation of V_x was multiplied by the cosine of the angle of the meter to the flow. The relative error calculation now becomes

$$RE\ (\%) = [(\hat{V}_x * \cos\theta_z - V_x)/V_x] * 100$$

The data for each of the rotors have been plotted in Figures 17 to 20. These data are listed in Appendix G.

Expectedly, all of the rotors underestimate V_x for the majority of situations once the cosine correction is applied. Other than the fact that the meters are now underestimating V_x, rather than overestimating V_x, the magnitude of the RE (%) values is basically the same for angles between about 20 degrees to the left and 20 degrees to the right. The benefit of the cosine correction becomes evident in the RE (%) values for the extreme angles of departure. Even at angles of 30 degrees, all the rotors now estimate V_x within 5% for most of the velocities. Without the cosine correction the meters had relative errors of upwards of 15%. The elliptical frontsides of P-3 and P-4 result in the smallest RE (%) values for the extreme angles of 30 degrees. The cosine correction overcompensates for P-1 and 1-179 at these angles.

7. DESIGN CONSIDERATIONS

The following discussion combines the rotor response theory from Section 2 with the results of the analyses from Section 5. In using the two aforementioned sections, it is possible to theoretically discuss how the response and behaviour of the plastic rotors may be improved over the current designs. In examining equations (3), (4), and (6)

$$T_1 = (1/2)\rho C_{D1} A (v - wr)^2 r \qquad (3)$$

$$T_2 = (1/2)\rho C_{D2} A (v + wr)^2 r \qquad (4)$$

$$w(t) = \frac{T_1 - T_2}{b} \left(1 - e^{(-b/I)t}\right) \qquad (6)$$

it can be seen that rotor response and behaviour are a function of C_{D1}, C_{D2}, b, and I, where these coefficients are as previously defined.

The magnitude of the difference in $(T_1 - T_2)$ causes the rotor to turn. The only parameters that are not common in equations (3) and (4) are the drag coefficient for the backside of the cups, C_{D1}, and the drag coefficient for the frontside of the cups, C_{D2}. The larger the difference between the drag coefficients, the larger the difference in the torques that cause the rotor to turn. It is desirable to maximize the difference between T_1 and T_2. In addition, it is desirable to have a rotor that can quickly respond to the applied torques. A quick response is accomplished by selecting a cup design with the least mass. This "least mass" design should be accompanied with shapes of rotors that have the largest difference in frontside and backside drag coefficients. A more hollowed back design of the plastic, elliptically shaped rotor will go the farthest in accomplishing these criteria.

The friction coefficient, b, of equation (6) influences several things: the flow velocity (threshold velocity) at which an experimentally repeatable rotation of the rotor begins; the rate at which the rotor accelerates or decelerates; and the rate of rotation, w, of the rotor once it has accelerated or decelerated to steady state. This friction coefficient includes all the friction generated by the pivot, cat whisker pickup, and the gears and bushings in the chamber. The standard Spin Test shows that the torque caused by friction is very small. However, the Inverted Spin Test shows that the friction can be increased significantly if

the rotor is lifted by upward velocity components and the rotor shaft pivots on the chamber cap. This is a design problem with the rotor shaft and upper pivot rather than with the rotor. This condition is worsened when the meter has been retrofitted with the fibre optic conversion kit.

The other influencing parameter is the moment of inertia, I. I has no effect on steady state rotation assuming steady state can be reached. However, I influences the threshold velocity and the rate of acceleration or deceleration of the rotor. The mass, m, of the rotor has a significant influence on I since $I = mk^2$. Due to the geometry of the rotor it would be difficult to reduce the radius of gyration, k, significantly. However, it is possible to reduce the mass of the rotor. This could be accomplished for the plastic rotors by completely hollowing the cups. Reducing the mass of the rotor would lower the threshold velocity because the threshold velocity occurs at the onset of acceleration of the rotor, and acceleration is a function of mass. A rotor of reduced mass would also respond quicker to changes in velocity enabling more accurate measurements to be taken.

The current designs of plastic rotors have not yet achieved the largest mass reduction or largest torque for a given velocity field. The attempt at hollowing out the back of P-4 was an improvement over the WSC standard plastic rotor, which has solid cups. Casting the rotor in a hollowed back mold would likely be the easiest method to construct a hollowed cup. It is realized that this may complicate casting and manufacturing, but is necessary if accuracy of the meter is sought. Care would have to

be taken to ensure that the walls of the cup are thick enough to maintain an acceptable level of durability. The hollowing of the cups would significantly increase the difference in the drag coefficients that result in torque. This would result in higher angular velocities, w, of the rotor for a given flow velocity. The decrease in mass due to hollowing would translate into better response characteristics.

The mass of the current plastic rotors is approximately 50% greater than the mass of the standard metal rotor (Table 1). This extra mass, as well as rotor shape, contributes to increasing the threshold velocity of the rotors as well as making them respond slower to changing flow velocities as compared to the metal rotors. Hollowing of the cups would reduce the mass greatly. For example, hollowing P-1 so it is the same as 1-179 will result in an 87% reduction in mass over the solid P-1 design. P-1 would then have a mass of about 0.026 kg verses 0.202 kg for the current P-1 design and 0.151 kg for 1-179. Unfortunately, such a thin walled cup may not be durable, but more reasonable wall thicknesses would still result in a rotor of less mass than the metal rotor.

The weight in water of the plastic rotors is about 43% of the submerged weight of the metal rotors. Reductions in mass will result in the submerged weight of the plastic rotors to become lighter even though the reduced volume decreases the buoyant force acting on the rotor. The submerged weight of P-1 would then be about 0.069 N as compared to 0.52 N for the current P-1 design and 1.29 N for 1-179. The decrease in submerged weight will reduce the friction resulting from the bottom pivot slightly. However,

plastic rotors with very light submerged weights will be affected by vertical velocity components to a much larger degree as there will be larger forces pushing the rotor shaft up into the chamber cap. There will be less resultant forces pulling the rotor down, resulting in more friction being generated from the existing design of the upper portion of the rotor shaft.

The upper pivot of the rotor shaft should be designed similar to the existing lower pivot, but possibly with a spring loaded pivot to reduce the potential for damaging the surface. This would likely remove the effects that upward velocity components have on the friction coefficient, b. The fibre optic pickup needs a similar redesign as the Inverted Spin Test shows that it has more friction than the standard cat whisker assembly. The combination of a lighter submerged weight plastic rotor with the current optical pickup design would result in a meter that would be more affected by vertical velocity components than any of the meters tested.

8. DISCUSSION

The lack of multiple trial testing of the rotors has made the interpretation of the collected data speculative, especially with respect to the effects of velocity on the magnitude of the relative error. Some of the graphs indicate that the magnitude of the RE (%) values are, for any given angle, independent of velocity. Other graphs indicate the converse. More data are required to prove or disprove whether the magnitude of the RE (%) values are a

function of velocity.

The results of the analyses indicate that a rotor with cups that are completely hollow will slip less as water moves past it, regardless of velocity, when compared to solid or slightly hollowed cup designs. This implies that such a rotor would have a higher angular velocity, w, and therefore would have a larger number of revolutions, N, over any given time. This is expected as the difference in the drag coefficients C_{D1} and C_{D2} characterizes the shape of the rotor. For the metal rotor, 1-179, equations (3) and (4) indicate that the large difference in the drag coefficients causes the rotor to turn more efficiently than its plastic counterparts. When low velocities are encountered in the field the rotor may be turning very slowly. Rotors with solid cups will turn even more slowly. Theoretically, the threshold velocity of the hollowed rotor should be less than that of the solid rotor.

The effects of vertical and horizontal departures were analyzed in an attempt to determine the effects of vertical and sideways velocity components on a meter's ability to estimate the actual downstream flow velocity. The results of the analyses on the vertical departure data indicate three things: (i) there is an inherent design problem with the upper pivot that is currently being used to house the rotorshaft; (i) rotors that use cups with hollowed backs are affected the least by vertical velocity components; and (iii) cups with elliptical frontsides are less sensitive to vertical velocity components than conical cups. All of the rotors underestimated the actual downstream velocity for the majority of conditions.

The results of the analysis on the horizontal departure data indicate two things: (i) for angles smaller than about 20 degrees, to the left and the right, all rotors estimate the actual downstream velocity with basically the same accuracy, and (ii) for angles larger than 20 degrees, the hollow cups of 1-179 where superior to the other rotors in estimating the true downstream velocity. The rotors with conical frontsides are not as predictable in their low velocity behaviour as the elliptical frontside rotors. All of the rotors overestimated the actual downstream velocity for the majority of conditions.

Providing that the angle θ_z can be determined in the field, the application of a cosine correction to horizontal velocity data caused all of the rotors to underestimate, rather than overestimate, the actual downstream velocity for the majcrity of conditions. The application of the cosine correction reduced the magnitude of the relative errors only for angles greater than about 20 degrees to the left and to the right. The rotors with elliptical frontsides gave the most accurate downstream velocity estimations for these extreme angles. The cosine correction was too large a correction, for extreme angles, for the rotors with conical frontsides.

One field situation that has not been discussed is the measurement of velocity under ice conditions. Slush ice, sometimes encountered in these situations, is suspended in the water and may adhere to the inside of the cups of a standard metal rotor. The accumulated ice would change both the mass and the backside drag coefficients of the rotor. This would change the response and behaviour of the

rotor in an unpredictable manner. The metal rotor may behave more akin to P-1 if the cups were completely filled with ice. Figure 6 shows that the behaviour of P-1 is significantly different from that of the metal rotor, 1-179. Therefore, if the metal rotor is behaving like P-1 the calibration equation of the metal rotor would not be representative of the metal rotor's behaviour. Until more data are collected on the effects of slush ice on the standard metal rotor, P-3 will give more accurate estimations of velocity under these conditions.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

1. Data that reflect upward vertical velocity components indicate that the Price meter assembly is improperly designed to monitor flow conditions of this nature.

2. The Inverted Spin Test indicates that the fibre optic pickup assembly causes considerably more friction when vertical velocity components are present than the conventional cat whisker electronic pickup head. The fibre optic conversion kit is improperly designed and will result in decreased accuracy of flow estimates when vertical velocity components are present.

3. For the majority of conditions, vertical velocity components cause all of the rotors to significantly underestimate the actual downstream velocity. This error can range from 11% for 15 degrees (above the horizontal plane) for the steel rotor to 21% at 15 degrees (above the horizontal plane) for the WSC plastic rotor. The hollowed cup of the metal rotor is affected the least by vertical velocity components.

4. For the majority of conditions, sideways velocity components cause all of the rotors to significantly overestimate the actual downstream velocity. This error can range from 12% for 30 degrees (left of the vertical plane) for the steel rotor to 17% at 30 degrees (left of the vertical plane) for the WSC

plastic rotor. The metal rotor was affected the least by sideways velocity components for most situations tested. The elliptical frontside shapes of two of the plastic rotors made their low velocity behaviour more predictable than the conically shaped rotors.

5. The application of a cosine correction, to sideways velocity fields, improved the estimation of the actual downstream velocity, for all rotors, for angles greater than about 20 degrees to the left and the right. Errors in the velocity estimation are reduced to less than about 5% for all of the rotors. There is no significant benefit of using a cosine correction for angles smaller than about 20 degrees.

6. Overall, considering all three flow situations and the rotor designs, the metal rotor is more accurate than the alternative designs at estimating the actual downstream velocity. The metal rotor is affected the least by vertical and sideways velocity components. Its relative errors in measurement are independent of velocity for the most part.

9.2 Recommendations

9.2.1 Design

A) In order to improve upon the performance of the current plastic rotor, the following design alteration is recommended. A plastic rotor should be cast that has cups with an elliptical frontside and a completely hollowed backside. Testing should be performed on a prototype of the recommended rotor to ensure that it provides better response and accuracy than the metal rotor.

B) In order to improve upon the performance of the Price 622-AA meter, the upper portion of the shaft on which the rotor is attached requires modification to reduce friction when upward velocity fields may be present. The following alterations to the meter are recommended:

1. The upper pivot of the standard cat whisker head should be modified to have friction characteristics similar to the existing lower pivot.

2. The upper pivot of the fibre optic pickup assembly should be modified to have friction characteristics similar to the existing lower pivot.

9.2.2 Operational

1. The fibre optic conversion kit as presently configured can lead to estimates of velocity that are more inaccurate than the standard cat whisker head. The fibre optic conversion kit is not recommended for WSC use until suitable modifications to the friction characteristics of the assembly have been made.

2. Rigorous laboratory testing of modifications to the meter is recommended prior to their adoption. Testing ensures the accuracy of the meter is not inadvertently decreased. This implies that the fibre optic pickup head or a modified top pivot or any other modification to the standard Price meter should be exhaustively tested and certified as being of similar or increased accuracy than current standards prior to their adoption for field use.

3. The standard metal rotor with the standard cat whisker head should be used for field use until conditions of (2) above are met for any modification of its design.

4. The WSC plastic rotor should be used when ice adheres to the inside of the metal rotor.

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Table 1. Weight and mass of rotors
(Engel et al. 1986)

Rotor	Weight (N)	Mass (kg)	Submerged Weight (N)
1–179	1.48	0.151	1.29
P–1	1.98	0.202	0.52
P–3	2.40	0.245	0.57
P–4	2.16	0.220	0.57

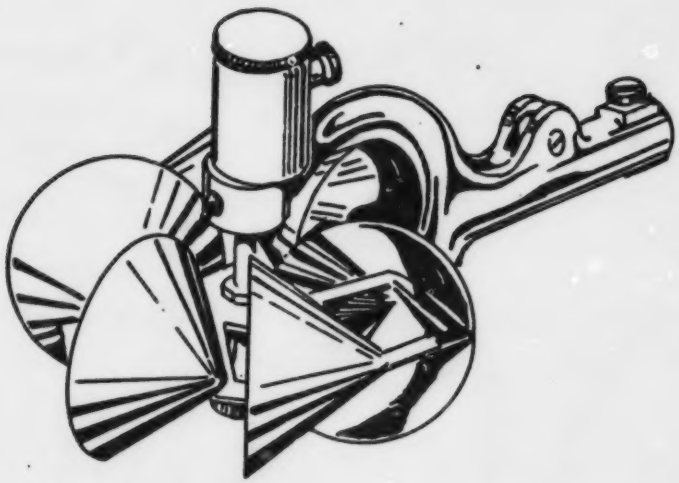
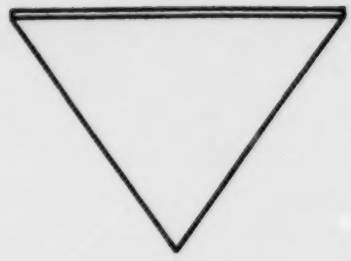
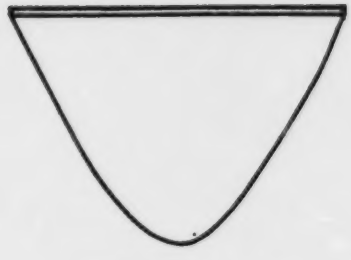


Figure 1. Price meter with metal rotor
(Engel et al. 1986)



ROTOR P-1
(U.S.G.S.)



ROTOR P-3
(W.S.C.)

ROTOR P-4

Figure 2. Cup designs of plastic rotors
(Engel et al. 1986)

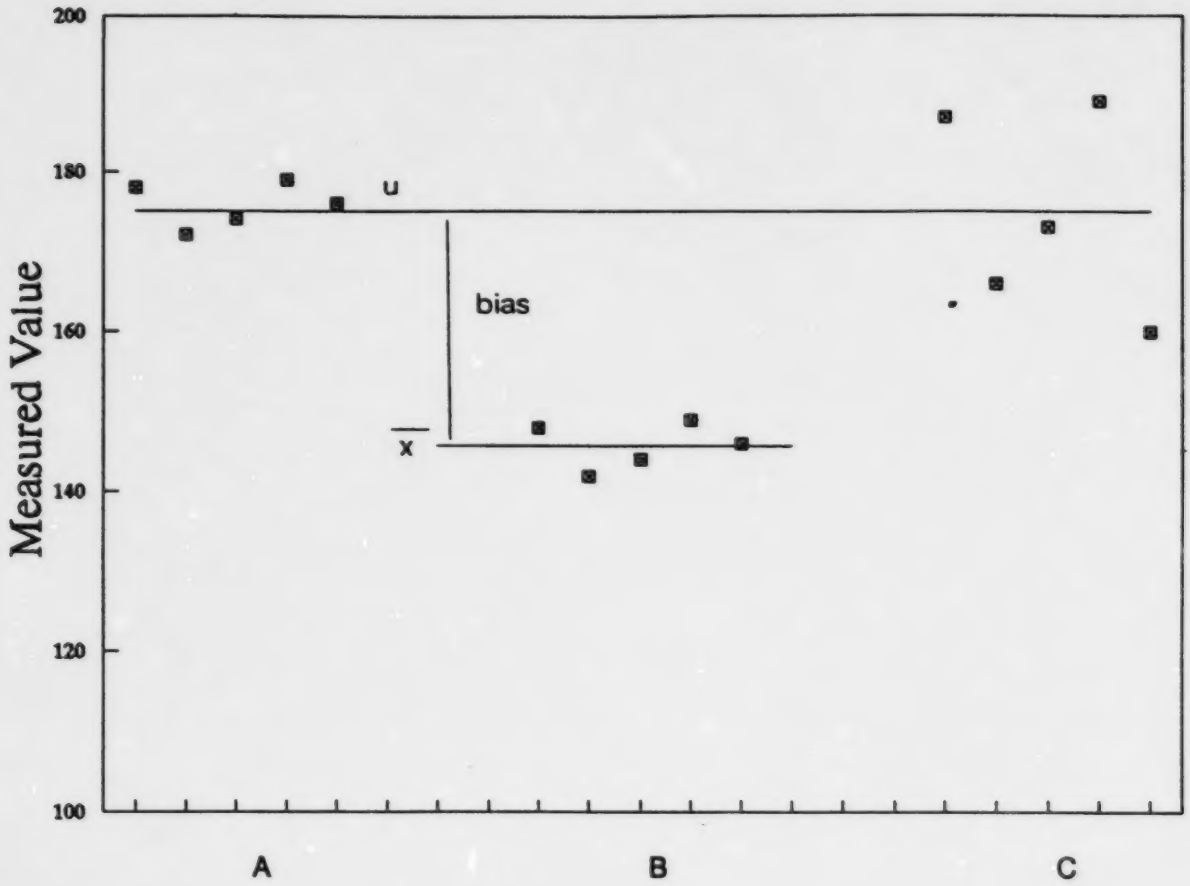


Figure 3. Effects of bias and precision on accuracy

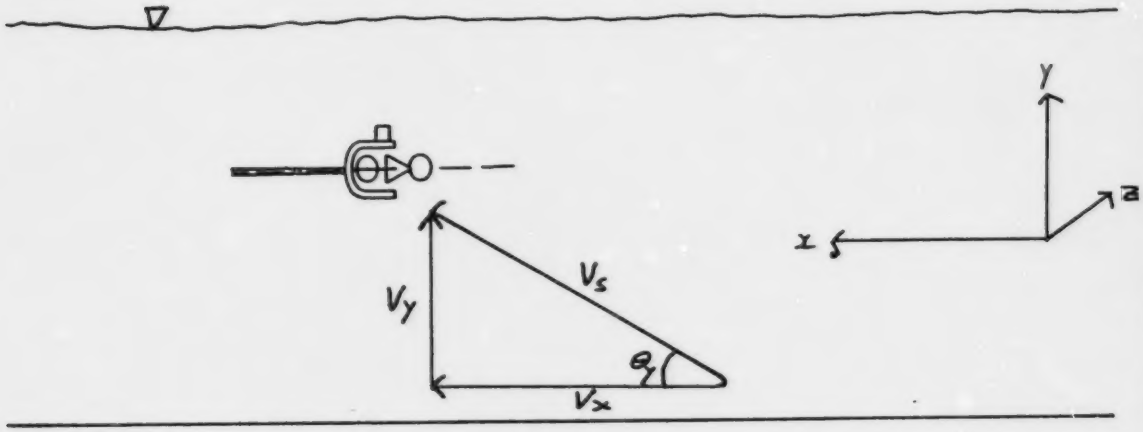


Figure 4. Actual field conditions

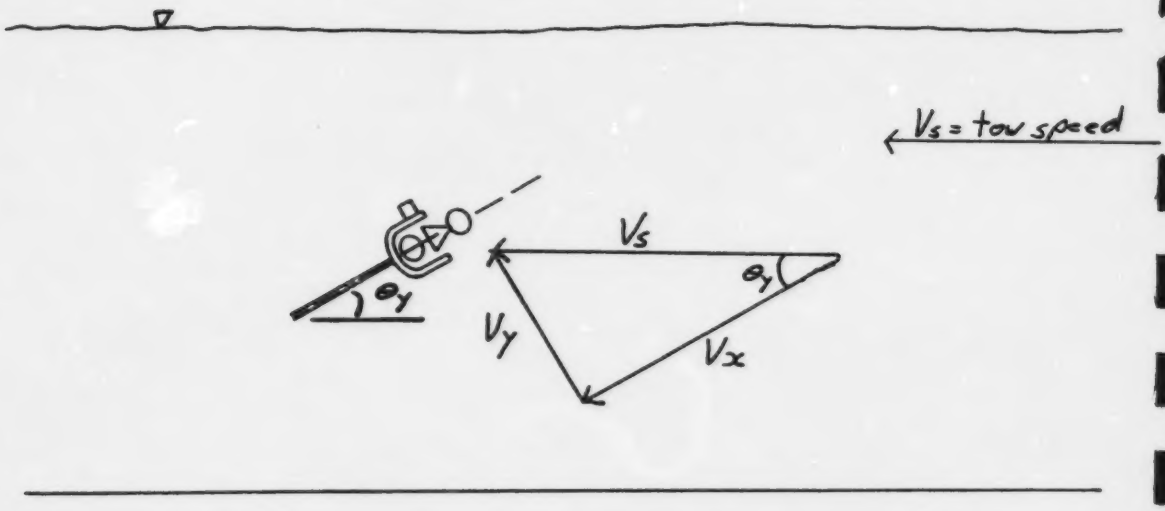


Figure 5. Tow tank simulation

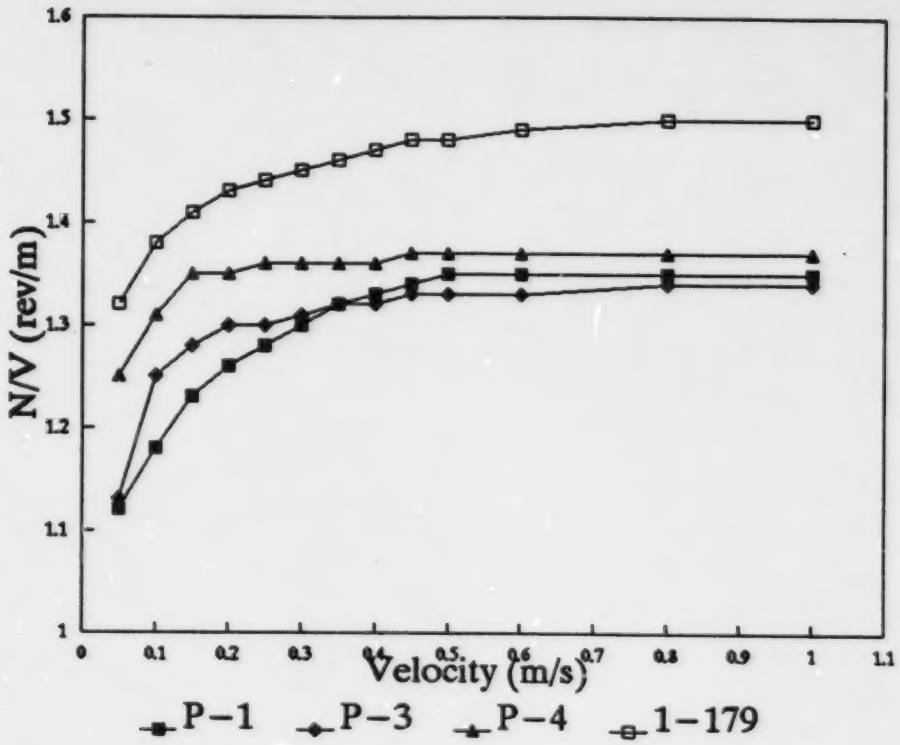
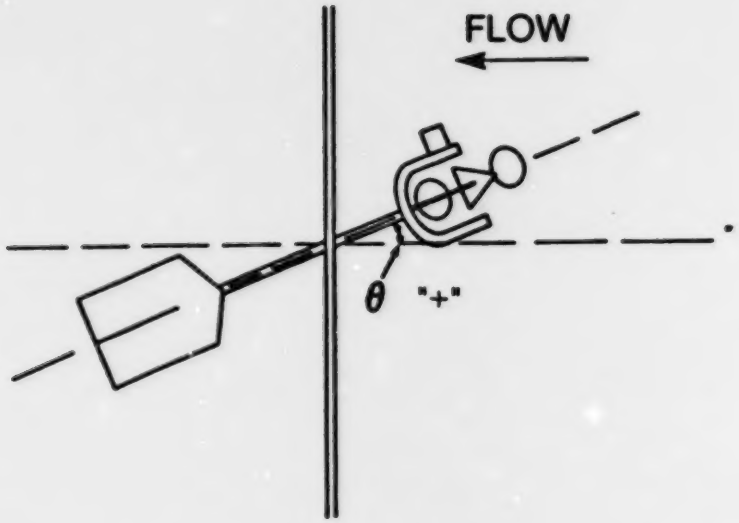
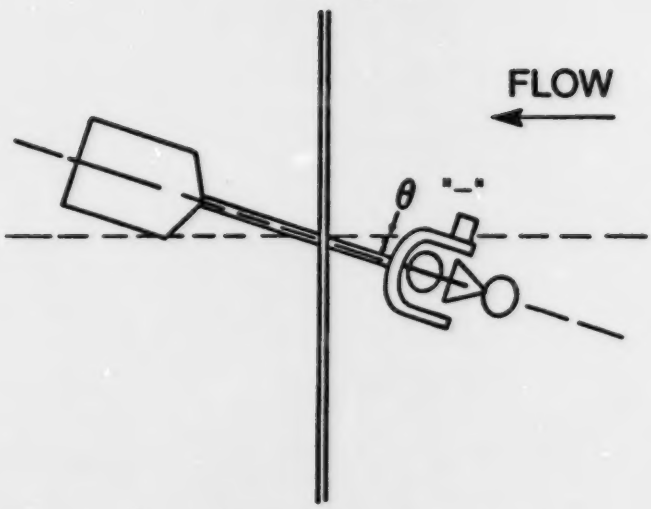


Figure 6. Behavior of rotors when placed normal to flow



ANGLE ABOVE HORIZONTAL PLANE



ANGLE BELOW HORIZONTAL PLANE

Figure 7. Departures in vertical alignment
(Engel et al. 1979)

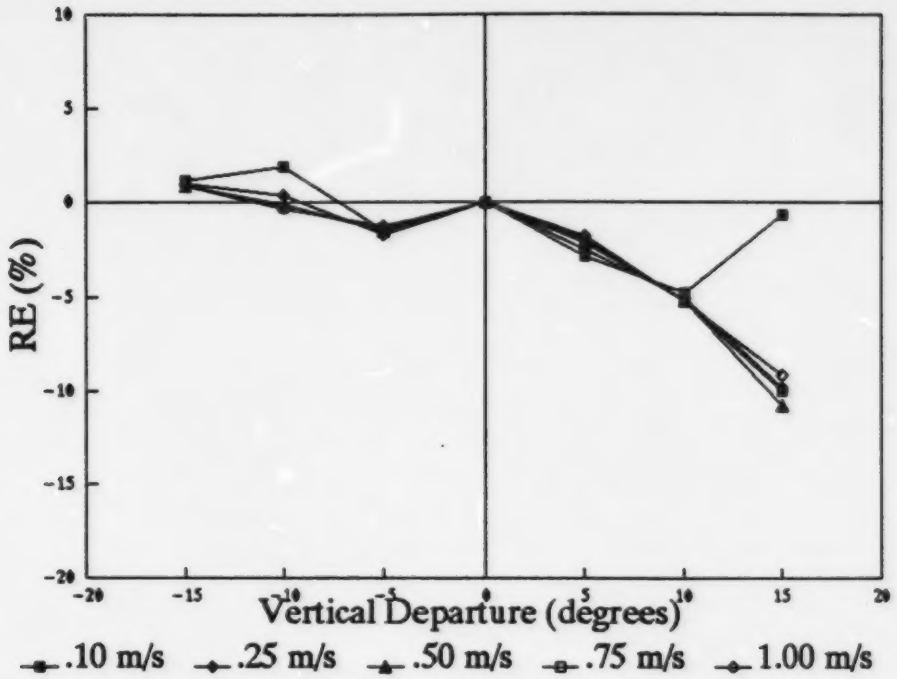


Figure 8. Effects of vertical departure on the relative error in estimation of Vx for the standard metal rotor 1–179

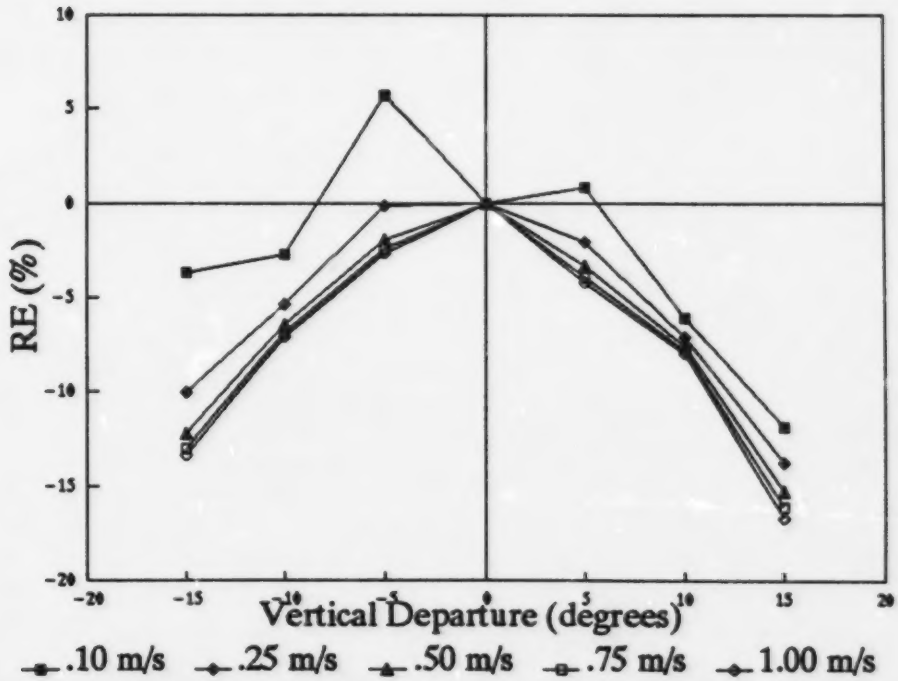


Figure 9. Effects of vertical departure on the relative error in estimation of Vx for the U.S.G.S. rotor P–1

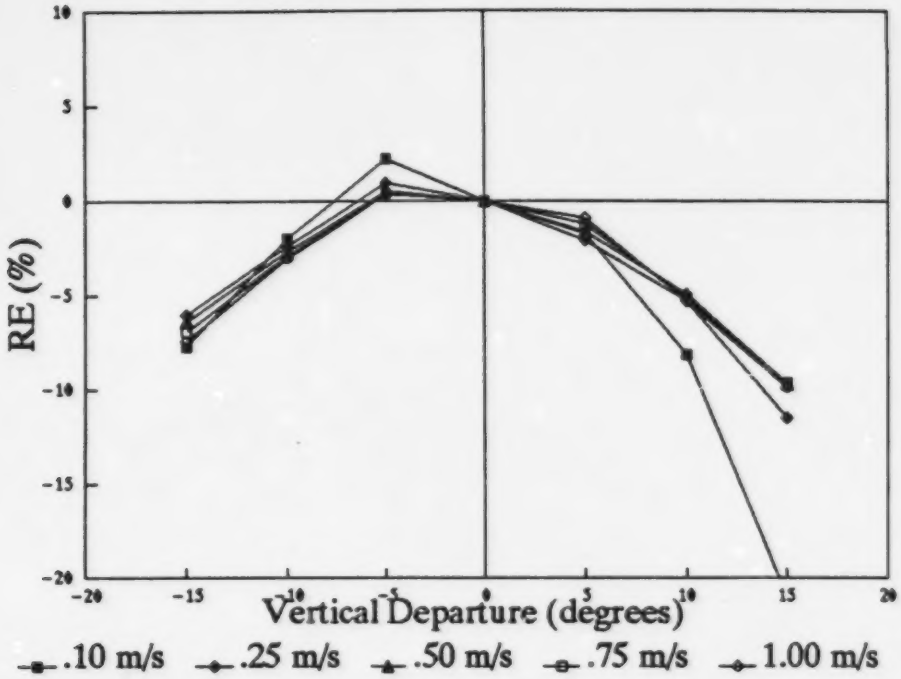


Figure 10. Effects of vertical departure on the relative error in estimation of Vx for the W.S.C. plastic rotor P–3

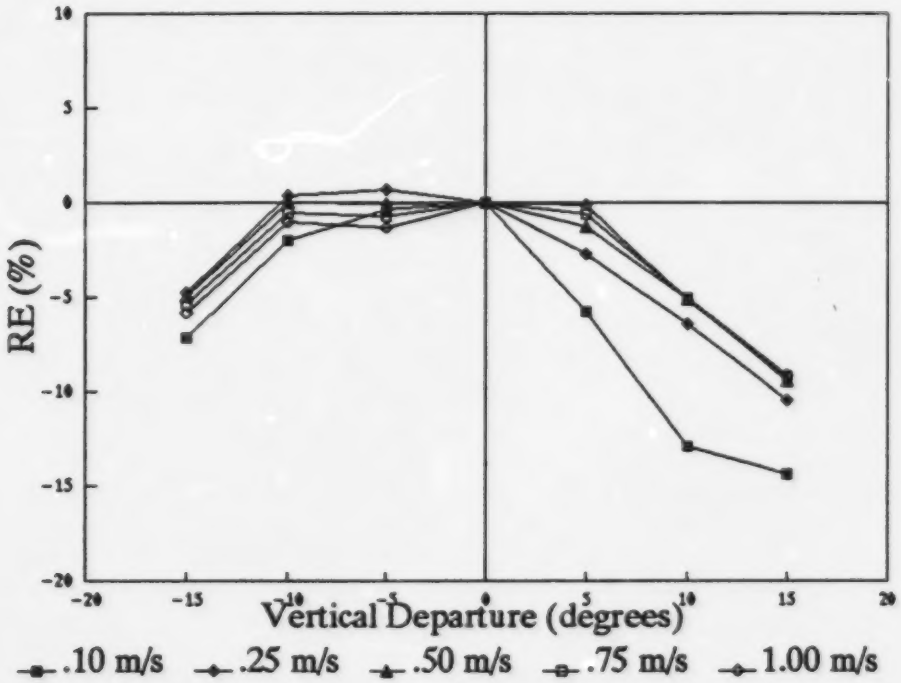


Figure 11. Effects of vertical departure on the relative error in estimation of Vx for P–4

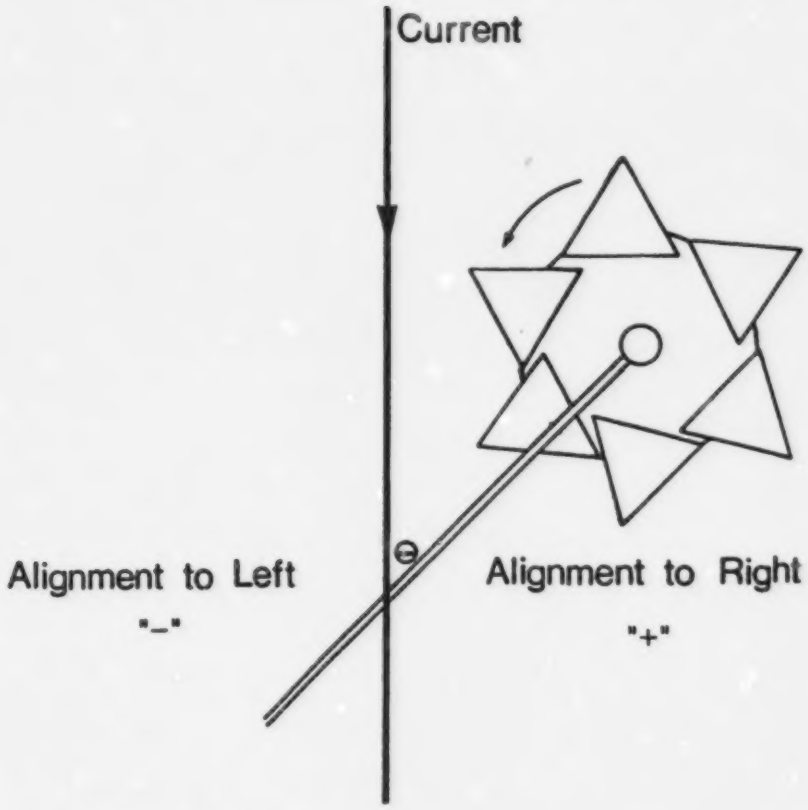


Figure 12. Departures in horizontal alignment
(Engel et al. 1978)

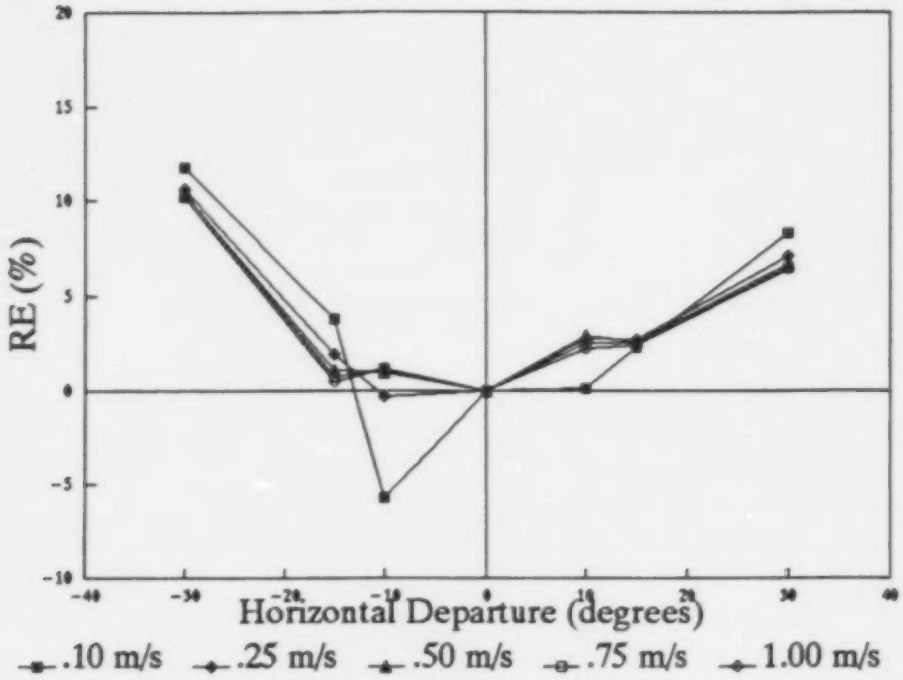


Figure 13. Effects of horizontal departure on the relative error in estimation of Vx for the standard metal rotor 1–179, 1–061

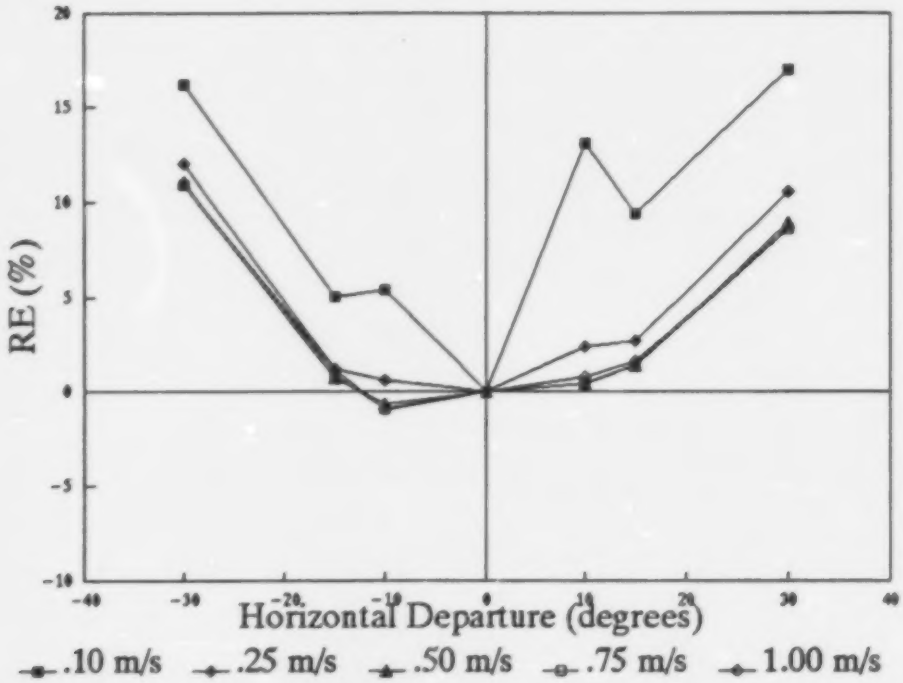


Figure 14. Effects of horizontal departure on the relative error in estimation of Vx for the U.S.G.S. plastic rotor P–1

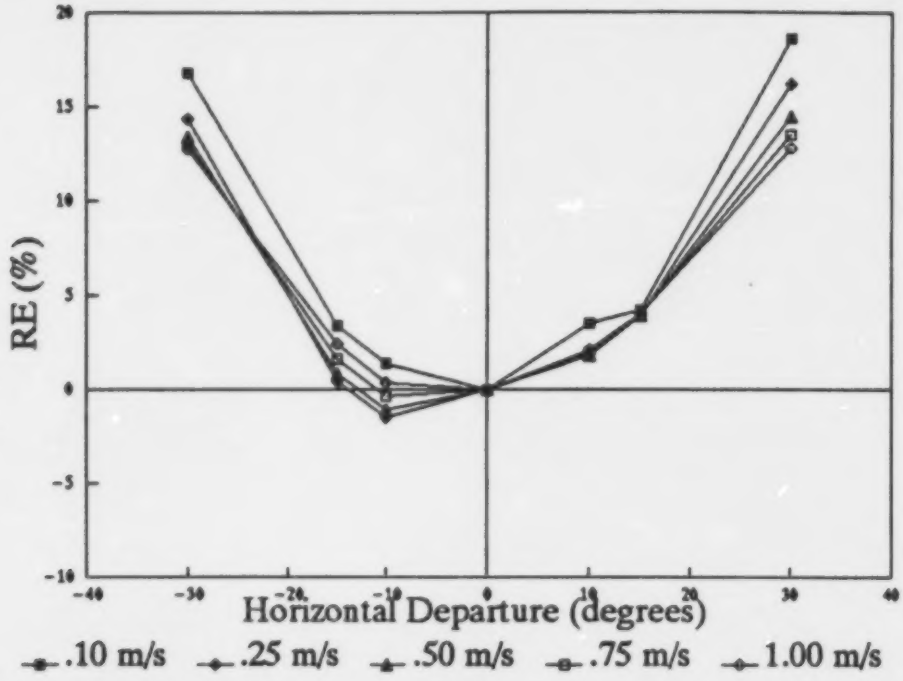


Figure 15. Effects of horizontal departure on the relative error in estimation of Vx for the W.S.C. plastic rotor P–3

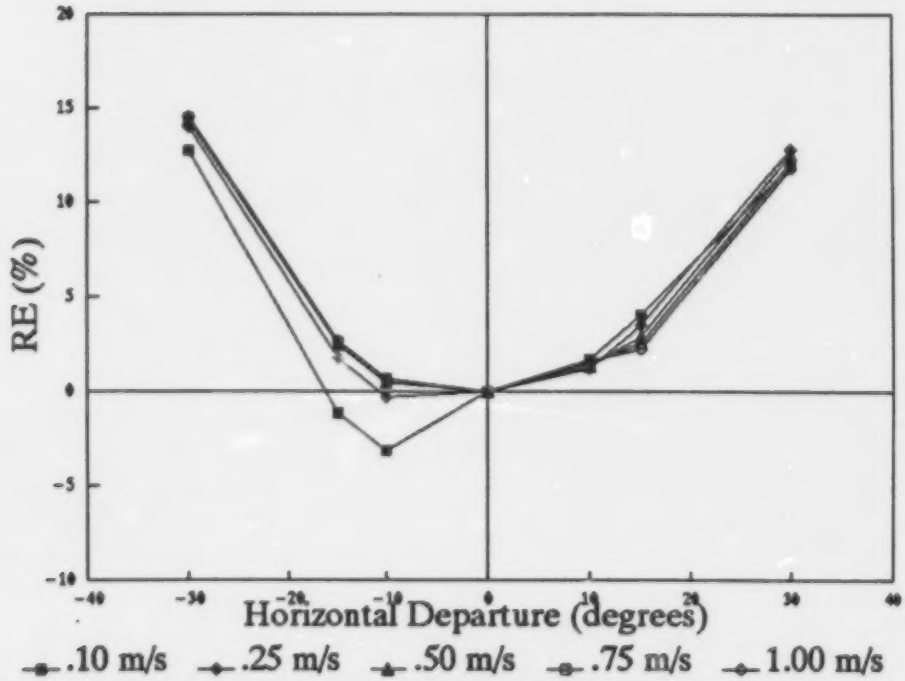


Figure 16. Effects of horizontal departure on the relative error in estimation of Vx for the P–4

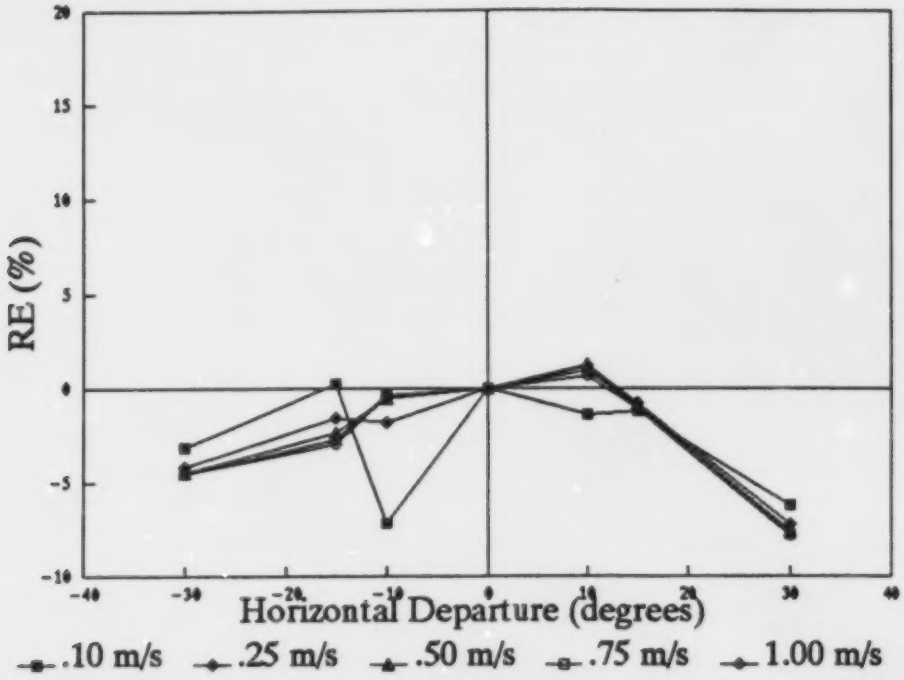


Figure 17. Effects of horizontal departure on the cosine corrected relative error in estimation of Vx for the standard metal rotor 1–179, 1–061

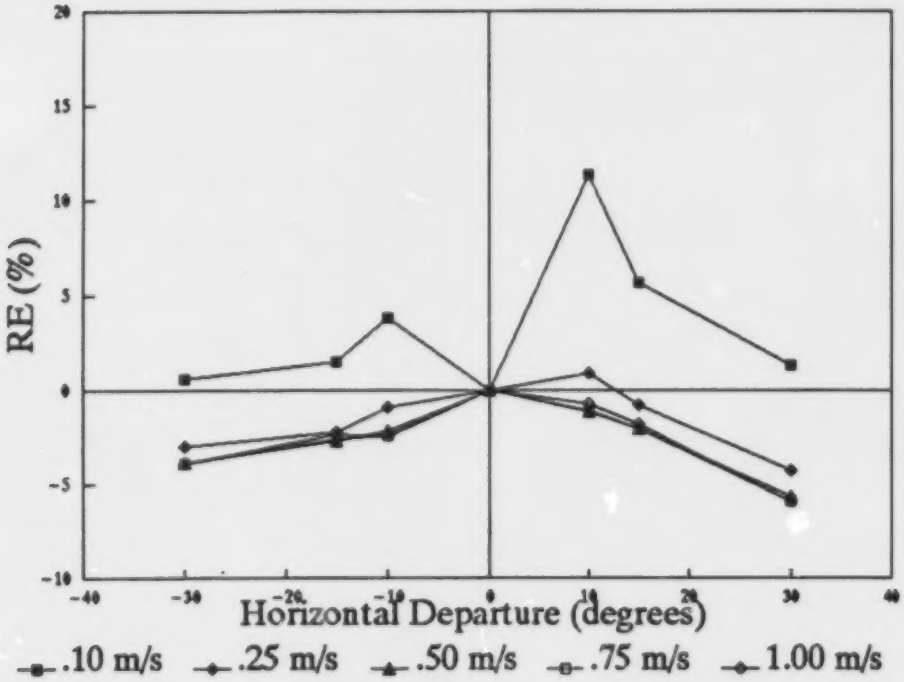


Figure 18. Effects of horizontal departure on the cosine corrected relative error in estimation of Vx for the U.S.G.S. plastic rotor P–1

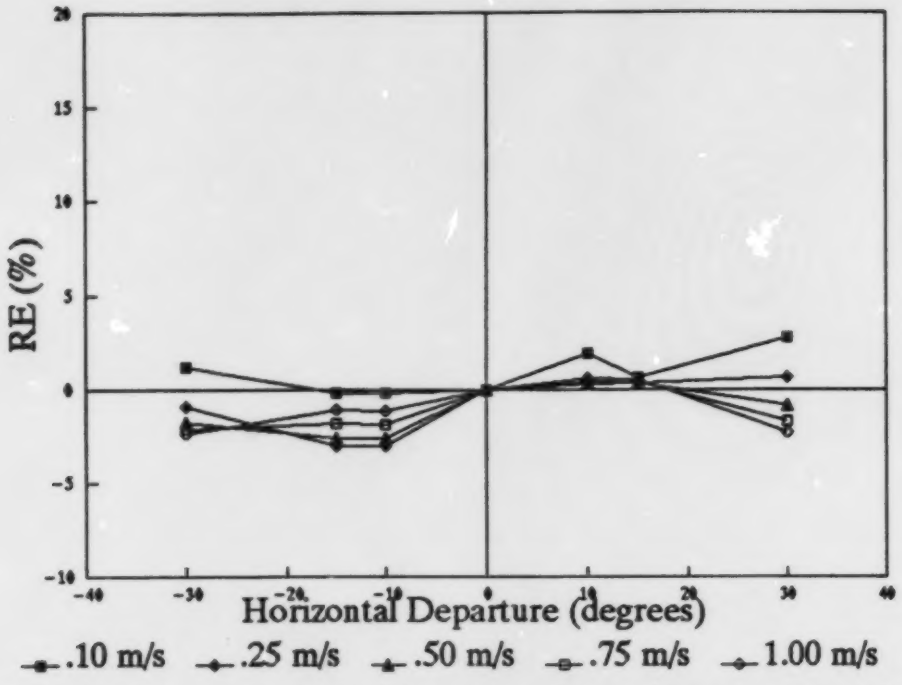


Figure 19. Effects of horizontal departure on the cosine corrected relative error in estimation of Vx for the W.S.C. plastic rotor P−3

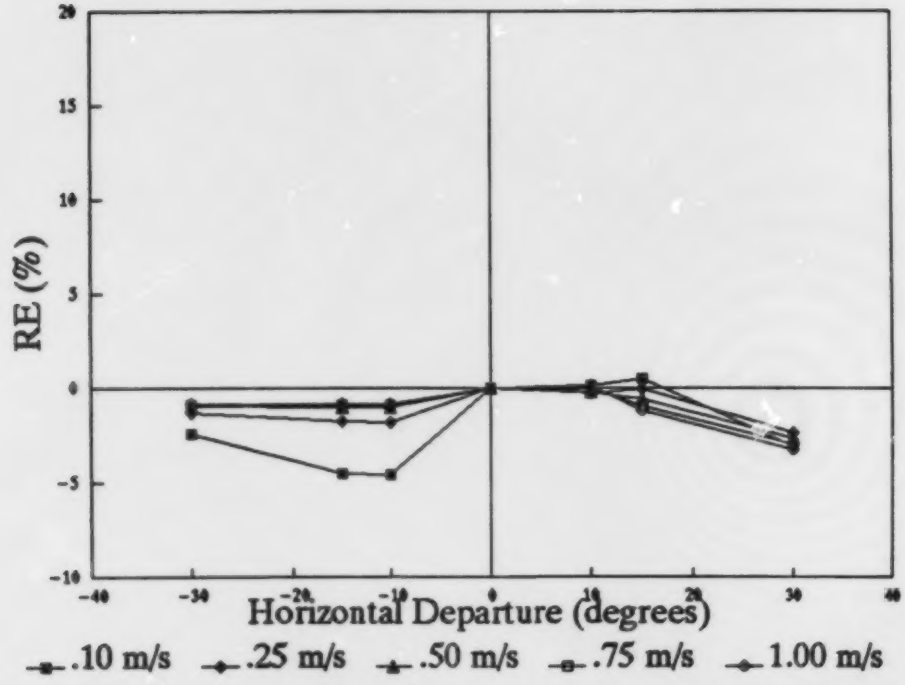


Figure 20. Effects of horizontal departure on the cosine corrected relative error in estimation of Vx for P−4

Appendix A - Explanation of data and methods

The data extracted from the three NWRI reports are (N/Vo) values for various Vo data. The velocity data collected by NWRI were labelled "Vo" in their reports. "Vo" values correspond to the "V_s" values used in this report. The V_s values are the velocities that the meters were towed through the tank. N is the number of rotor rotations per second. The N values were back calculated from the (N/V_s) values by multiplying the (N/V_s) values by the corresponding V_s. The N values, for the corresponding V_s values, were calculated for all rotors for all vertical and horizontal angles of departure. The angle of departure is indicated by the value next to "N" (ie N5 means the number of rotor rotations per second when placed at a 5 degree departure). This calculation provided the basic data used in the vertical and horizontal departure sections of this report. These data are listed in Appendix B.

The relative error, RE (%), of a meter's estimation of the actual downstream velocity is

$$RE\ (\%) = [(\widehat{Vx} - Vx)/Vx] * 100$$

where $\widehat{V}_x$ is the velocity indicated by the meter, and V_x is the actual downstream velocity. The V_x values used in this report were 0.10, 0.25, 0.50, 0.75, and 1.00 m/s. The $\widehat{V}_x$ values used were generated from calibration equations that model the N and V_x data. The actual velocity acting directly on, or planar too, the rotor is V_x. The V_s values were converted to V_x values by multiplying the V_s value by the cosine of the angle that the meter was towed at.

For each rotor, calibration equations were derived for each of the

angles of vertical and horizontal departure. The calibration equations were derived using least squares regression. Power functions were used in some cases to improve the "fit" of the equation to the data. For the most part, the residual errors of the calibration equations were kept within plus or minus 1%. The calibration equations are listed in Appendix C.

For a given angle of departure and V_x velocity, the N value was calculated using the calibration equation specific to the angle of interest. This N value would be the value that the meter would indicate to a technician in the field. The N value is then plugged into the "standard" calibration equation for the meter. The "standard" calibration equation describes the rotor's behaviour when the meter is perfectly aligned with the downstream flow of the water. "Standard" calibration equations were derived for all the rotors in the same manner as the calibration equations were derived for the various angles of departure. The "standard" calibration equations are also listed in Appendix C. The velocity that the "standard" calibration gives, using the N value calculated from the calibration equation for the angle of interest, is the estimated downstream velocity, $\hat{V}_x$. This procedure simulates how the velocity is actually estimated in the field. The RE (%) was then calculated using this $\hat{V}_x$ value. The RE (%) calculations are in Appendices E, F, and G.

More descriptive nomenclature was used in the spreadsheets to make it easier to perform the various calculations. The nomenclature used in Appendices E, F, and G is explained as follows. V_x is the actual downstream velocity of interest. The V_x values selected

were 0.10, 0.25, 0.50, 0.75, and 1.00 m/s. In Appendices E, F, and G the number of revolutions that a particular calibration equation gives, for a specified V_x value, is N(angle). For example, N5 is the number of rotor revolutions that the meter would indicate when aligned at a 5 degree angle of departure. N5 is from the calibration equation derived for the 5 degree departure. The N(angle) value is then plugged into the "standard" calibration equation. The estimated velocity is then Vx(angle). In the above example, Vx(angle) would be Vx5. Vx(angle) is the same as $\hat{V}_x$ used in the body of the report. The RE (%) calculations were then calculated out using the equation

$$RE\ (\%) = [(Vx(angle) - V_x)/V_x] * 100$$

The above equation is the same as

$$RE\ (\%) = [(\hat{V}_x - V_x)/V_x] * 100$$

which is the equation discussed in the report.

Appendix B - Extracted performance data

Meter 1–179
For Angles Below Horizontal Plane

Vs (m/s)	N0/Vs	N0	N5/Vs	N5	N10/Vs	N10	N15/Vs	N15
0.05	1.32	0.066	1.28	0.064				
0.10	1.38	0.138	1.35	0.135	1.37	0.137	1.33	0.133
0.15	1.41	0.212	1.37	0.206	1.40	0.210	1.37	0.206
0.20	1.43	0.286	1.39	0.278	1.42	0.284	1.39	0.278
0.25	1.44	0.360	1.42	0.355	1.43	0.358	1.41	0.353
0.30	1.45	0.435	1.43	0.429	1.44	0.432	1.42	0.426
0.35	1.46	0.511	1.43	0.500	1.44	0.504	1.43	0.500
0.40	1.47	0.588	1.44	0.576	1.45	0.580	1.43	0.572
0.45	1.48	0.666	1.44	0.648	1.45	0.653	1.44	0.648
0.50	1.48	0.740	1.45	0.725	1.46	0.730	1.44	0.720
0.75	1.49	1.118	1.47	1.103	1.47	1.103	1.46	1.095
1.00	1.50	1.500	1.48	1.480	1.47	1.470	1.46	1.460
1.50	1.50	2.250	1.48	2.220	1.47	2.205	1.46	2.190
2.00	1.50	3.000	1.48	2.960	1.47	2.940	1.46	2.920

Meter 1 – 179
For Angles Above Horizontal Plane

Vs (m/s)	N0/Vs	N0	N5/Vs	N5	N10/Vs	N10	N15/Vs	N15
0.05	1.32	0.066						
0.10	1.38	0.138	1.33	0.133	1.30	0.130	1.30	0.130
0.15	1.41	0.212	1.36	0.204	1.33	0.200	1.29	0.194
0.20	1.43	0.286	1.38	0.276	1.34	0.268	1.28	0.256
0.25	1.44	0.360	1.39	0.348	1.35	0.338	1.28	0.320
0.30	1.45	0.435	1.41	0.423	1.36	0.408	1.27	0.381
0.35	1.46	0.511	1.42	0.497	1.37	0.480	1.27	0.445
0.40	1.47	0.588	1.43	0.572	1.37	0.548	1.26	0.504
0.45	1.48	0.666	1.44	0.648	1.38	0.621	1.26	0.567
0.50	1.48	0.740	1.44	0.720	1.38	0.690	1.26	0.630
0.75	1.49	1.118	1.47	1.103	1.38	1.035	1.28	0.960
1.00	1.50	1.500	1.47	1.470	1.39	1.390	1.30	1.300
1.50	1.50	2.250	1.47	2.205	1.40	2.100	1.34	2.010
2.00	1.50	3.000	1.47	2.940	1.40	2.800	1.36	2.720

Meter P–1
For Angles Below Horizontal Plane

Vs (m/s)	N0/Vs	N0	N5/Vs	N5	N10/Vs	N10	N15/Vs	N15
0.05	1.12	0.056	1.07	0.054	0.79	0.040		
0.10	1.18	0.118	1.23	0.123	1.10	0.110	1.07	0.107
0.15	1.23	0.185	1.27	0.191	1.17	0.176	1.10	0.165
0.20	1.26	0.252	1.28	0.256	1.19	0.238	1.11	0.222
0.25	1.28	0.320	1.29	0.323	1.20	0.300	1.11	0.278
0.30	1.30	0.390	1.30	0.390	1.21	0.363	1.12	0.336
0.35	1.32	0.462	1.30	0.455	1.22	0.427	1.12	0.392
0.40	1.33	0.532	1.30	0.520	1.22	0.488	1.13	0.452
0.45	1.34	0.603	1.31	0.590	1.23	0.554	1.13	0.509
0.50	1.35	0.675	1.31	0.655	1.23	0.615	1.13	0.565
0.75	1.35	1.013	1.31	0.983	1.23	0.923	1.13	0.848
1.00	1.35	1.350	1.31	1.310	1.24	1.240	1.13	1.130

Meter P–1
For Angles Above Horizontal Plane

Vs (m/s)	N0/Vs	N0	N5/Vs	N5	N10/Vs	N10	N15/Vs	N15
0.05	1.12	0.056	1.02	0.051	0.62	0.031	0.52	0.026
0.10	1.18	0.118	1.16	0.116	1.07	0.107	0.95	0.095
0.15	1.23	0.185	1.22	0.183	1.13	0.170	1.02	0.153
0.20	1.26	0.252	1.24	0.248	1.16	0.232	1.07	0.214
0.25	1.28	0.320	1.26	0.315	1.18	0.295	1.08	0.270
0.30	1.30	0.390	1.27	0.381	1.20	0.360	1.08	0.324
0.35	1.32	0.462	1.28	0.448	1.21	0.424	1.08	0.378
0.40	1.33	0.532	1.28	0.512	1.21	0.484	1.08	0.432
0.45	1.34	0.603	1.29	0.581	1.22	0.549	1.08	0.486
0.50	1.35	0.675	1.29	0.645	1.22	0.610	1.08	0.540
0.75	1.35	1.013	1.29	0.968	1.22	0.915	1.09	0.818
1.00	1.35	1.350	1.29	1.290	1.22	1.220	1.09	1.090

Meter P–3
For Angles Below Horizontal Plane

Vs (m/s)	N0/Vs	N0	N5/Vs	N5	N10/Vs	N10	N15/Vs	N15
0.05	1.13	0.057	1.15	0.058	0.80			
0.10	1.25	0.125	1.27	0.127	1.18	0.118	1.08	0.108
0.15	1.28	0.192	1.30	0.195	1.24	0.186	1.15	0.173
0.20	1.30	0.260	1.31	0.262	1.25	0.250	1.18	0.236
0.25	1.30	0.325	1.32	0.330	1.26	0.315	1.19	0.298
0.30	1.31	0.393	1.32	0.396	1.26	0.378	1.19	0.357
0.35	1.32	0.462	1.32	0.462	1.26	0.441	1.19	0.417
0.40	1.32	0.528	1.33	0.532	1.27	0.508	1.19	0.476
0.45	1.33	0.599	1.33	0.599	1.27	0.572	1.20	0.540
0.50	1.33	0.665	1.33	0.665	1.27	0.635	1.20	0.600
0.75	1.34	1.005	1.34	1.005	1.28	0.960	1.20	0.900
1.00	1.34	1.340	1.34	1.340	1.28	1.280	1.20	1.200

Meter P–3
For Angles Above Horizontal Plane

Vs (m/s)	N0/Vs	N0	N5/Vs	N5	N10/Vs	N10	N15/Vs	N15
0.05	1.13	0.057	1.13	0.057	0.80			
0.10	1.25	0.125	1.20	0.120	1.10	0.110	0.92	0.092
0.15	1.28	0.192	1.23	0.185	1.18	0.177	1.03	0.155
0.20	1.30	0.260	1.26	0.252	1.20	0.240	1.08	0.216
0.25	1.30	0.325	1.27	0.318	1.22	0.305	1.12	0.280
0.30	1.31	0.393	1.28	0.384	1.23	0.369	1.13	0.339
0.35	1.32	0.462	1.29	0.452	1.23	0.431	1.14	0.399
0.40	1.32	0.528	1.30	0.520	1.23	0.492	1.14	0.456
0.45	1.33	0.599	1.30	0.585	1.24	0.558	1.15	0.518
0.50	1.33	0.665	1.31	0.655	1.24	0.620	1.15	0.575
0.75	1.34	1.005	1.32	0.990	1.25	0.938	1.16	0.870
1.00	1.34	1.340	1.32	1.320	1.25	1.250	1.17	1.170

Meter P–4
For Angles Below Horizontal Plane

Vs (m/s)	N0/Vs	N0	N5/Vs	N5	N10/Vs	N10	N15/Vs	N15
0.05	1.25	0.063	1.23	0.062	1.10	0.055	0.65	0.033
0.10	1.31	0.131	1.30	0.130	1.27	0.127	1.16	0.116
0.15	1.35	0.203	1.35	0.203	1.32	0.198	1.23	0.185
0.20	1.35	0.270	1.36	0.272	1.35	0.270	1.24	0.248
0.25	1.36	0.340	1.36	0.340	1.35	0.338	1.25	0.313
0.30	1.36	0.408	1.36	0.408	1.35	0.405	1.25	0.375
0.35	1.36	0.476	1.37	0.480	1.35	0.473	1.26	0.441
0.40	1.36	0.544	1.37	0.548	1.34	0.536	1.26	0.504
0.45	1.37	0.617	1.36	0.612	1.34	0.603	1.25	0.563
0.50	1.37	0.685	1.36	0.680	1.34	0.670	1.25	0.625
0.75	1.37	1.028	1.35	1.013	1.34	1.005	1.25	0.938
1.00	1.37	1.370	1.35	1.350	1.34	1.340	1.25	1.250

Meter P–4
For Angles Above Horizontal Plane

Vs (m/s)	N0/Vs	N0	N5/Vs	N5	N10/Vs	N10	N15/Vs	N15
0.05	1.25	0.063	1.10	0.055	0.86	0.043		
0.10	1.31	0.131	1.22	0.122	1.13	0.113	1.00	0.100
0.15	1.35	0.203	1.27	0.191	1.20	0.180	1.14	0.171
0.20	1.35	0.270	1.29	0.258	1.23	0.246	1.16	0.232
0.25	1.36	0.340	1.32	0.330	1.24	0.310	1.17	0.293
0.30	1.36	0.408	1.33	0.399	1.26	0.378	1.18	0.354
0.35	1.36	0.476	1.33	0.466	1.26	0.441	1.19	0.417
0.40	1.36	0.544	1.34	0.536	1.27	0.508	1.19	0.476
0.45	1.37	0.617	1.34	0.603	1.28	0.576	1.20	0.540
0.50	1.37	0.685	1.35	0.675	1.28	0.640	1.20	0.600
0.75	1.37	1.028	1.36	1.020	1.28	0.960	1.20	0.900
1.00	1.37	1.370	1.36	1.360	1.28	1.280	1.20	1.200

Meter 1–179
For Angles Left of Vertical Plane

Vs (m/s)	N0/Vs	N0	N15/Vs	N15	N30/Vs	N30
0.05	1.32	0.066				
0.10	1.38	0.138	1.38	0.138	1.33	0.133
0.15	1.41	0.212	1.39	0.209	1.35	0.203
0.20	1.43	0.286	1.41	0.282	1.36	0.272
0.25	1.44	0.360	1.42	0.355	1.38	0.345
0.30	1.45	0.435	1.43	0.429	1.39	0.417
0.35	1.46	0.511	1.44	0.504	1.40	0.490
0.40	1.47	0.588	1.44	0.576	1.41	0.564
0.45	1.48	0.666	1.45	0.653	1.41	0.635
0.50	1.48	0.740	1.45	0.725	1.42	0.710
0.75	1.49	1.118	1.45	1.088	1.43	1.073
1.00	1.50	1.500	1.45	1.450	1.43	1.430
1.50	1.50	2.250	1.45	2.175	1.43	2.145
2.00	1.50	3.000	1.45	2.900	1.43	2.860

Meter 1–061
For Angles Left of Vertical

Vo (m/s)	No/Vo	No	N10/Vo	N10
0.05	1.33	0.067		
0.10	1.37	0.137	1.27	0.127
0.15	1.40	0.210	1.33	0.200
0.20	1.42	0.284	1.38	0.276
0.25	1.43	0.358	1.41	0.353
0.30	1.44	0.432	1.43	0.429
0.35	1.46	0.511	1.44	0.504
0.40	1.46	0.584	1.45	0.580
0.45	1.47	0.662	1.46	0.657
0.50	1.48	0.740	1.47	0.735
0.75	1.48	1.110	1.47	1.103
1.00	1.48	1.480	1.47	1.470
1.50	1.48	2.220	1.47	2.205
2.00	1.48	2.960	1.47	2.940

Meter 1–179
For Angles Right of Vertical Plane

Vs (m/s)	N0/Vs	N0	N15/Vs	N15	N30/Vs	N30
0.05	1.32	0.066	1.32	0.066	1.25	0.063
0.10	1.38	0.138	1.35	0.135	1.29	0.129
0.15	1 41	0.212	1.39	0.209	1.31	0.197
0.20	1.43	0.286	1.42	0.284	1.32	0.264
0.25	1.44	0.360	1.43	0.358	1.33	0.333
0.30	1.45	0.435	1.44	0.432	1.34	0.402
0.35	1.46	0.511	1.45	0.508	1.35	0.473
0.40	1.47	0.588	1.45	0.580	1.36	0.544
0.45	1.48	0.666	1.46	0.657	1.36	0.612
0.50	1.48	0.740	1.47	0.735	1.37	0.685
0.75	1.49	1.118	1.48	1.110	1.38	1.035
1.00	1.50	1.500	1.48	1.480	1.38	1.380
1.50	1.50	2.250	1.48	2.220	1.38	2.070
2.00	1.50	3.000	1.48	2.960	1.38	2.760

Meter 1–061
For Angles Right of Vertical Plane

Vs (m/s)	N0/Vs	N0	N10/Vs	N10
0.05	1.33	0.067	1.33	0.067
0.10	1.37	0.137	1.36	0.136
0.15	1.40	0.210	1.41	0.212
0.20	1.42	0.284	1.43	0.286
0.25	1.43	0.358	1.46	0.365
0.30	1.44	0.432	1.48	0.444
0.35	1.46	0.511	1.49	0.522
0.40	1.46	0.584	1.49	0.596
0.45	1.47	0.662	1.49	0.671
0.50	1.48	0.740	1.49	0.745
0.75	1.48	1.110	1.48	1.110
1.00	1.48	1.480	1.48	1.480
1.50	1.48	2.220	1.48	2.220
2.00	1.48	2.960	1.48	2.960

Meter P–1
For Angles Left of Vertical Plane

Vs (m/s)	N0/Vs	N0	N10/Vs	N10	N15/Vs	N15	N30/Vs	N30
0.05	1.12	0.056	1.13	0.057	1.09	0.055	1.09	0.055
0.10	1.18	0.118	1.21	0.121	1.18	0.118	1.18	0.118
0.15	1.23	0.185	1.25	0.188	1.23	0.185	1.23	0.185
0.20	1.26	0.252	1.27	0.254	1.25	0.250	1.25	0.250
0.25	1.28	0.320	1.29	0.323	1.28	0.320	1.27	0.318
0.30	1.30	0.390	1.30	0.390	1.28	0.384	1.27	0.381
0.35	1.32	0.462	1.30	0.455	1.28	0.448	1.27	0.445
0.40	1.33	0.532	1.30	0.520	1.28	0.512	1.27	0.508
0.45	1.34	0.603	1.30	0.585	1.29	0.581	1.28	0.576
0.50	1.35	0.675	1.30	0.650	1.30	0.650	1.28	0.640
0.75	1.35	1.013	1.32	0.990	1.32	0.990	1.30	0.975
1.00	1.35	1.350	1.32	1.320	1.32	1.320	1.30	1.300

Meter P–1
For Angles Right of Vertical Plane

Vs (m/s)	N0/Vs	N0	N10/Vs	N10	N15/Vs	N15	N30/Vs	N30
0.05	1.12	0.056	1.15	0.058	1.13	0.057	1.15	0.058
0.10	1.18	0.118	1.32	0.132	1.25	0.125	1.20	0.120
0.15	1.23	0.185	1.33	0.200	1.27	0.191	1.22	0.183
0.20	1.26	0.252	1.32	0.264	1.28	0.256	1.23	0.246
0.25	1.28	0.320	1.32	0.330	1.29	0.323	1.24	0.310
0.30	1.30	0.390	1.32	0.396	1.29	0.387	1.25	0.375
0.35	1.32	0.462	1.31	0.459	1.30	0.455	1.25	0.438
0.40	1.33	0.532	1.31	0.524	1.30	0.520	1.26	0.504
0.45	1.34	0.603	1.31	0.590	1.30	0.585	1.26	0.567
0.50	1.35	0.675	1.31	0.655	1.31	0.655	1.27	0.635
0.75	1.35	1.013	1.33	0.998	1.32	0.990	1.27	0.953
1.00	1.35	1.350	1.35	1.350	1.33	1.330	1.27	1.270

Meter P–3
For Angles Left of Vertical Plane

Vs (m/s)	N0/Vs	No	N10/Vs	N10	N15/Vs	N15	N30/Vs	N30
0.05	1.13	0.057	1.21	0.061	1.21	0.061	1.21	0.061
0.10	1.25	0.125	1.24	0.124	1.24	0.124	1.25	0.125
0.15	1.28	0.192	1.26	0.189	1.26	0.189	1.28	0.192
0.20	1.30	0.260	1.26	0.252	1.26	0.252	1.30	0.260
0.25	1.30	0.325	1.26	0.315	1.26	0.315	1.30	0.325
0.30	1.31	0.393	1.27	0.381	1.27	0.381	1.30	0.390
0.35	1.32	0.462	1.27	0.445	1.27	0.445	1.30	0.455
0.40	1.32	0.528	1.28	0.512	1.28	0.512	1.30	0.520
0.45	1.33	0.599	1.29	0.581	1.29	0.581	1.31	0.590
0.50	1.33	0.665	1.30	0.650	1.30	0.650	1.31	0.655
0.75	1.34	1.005	1.32	0.990	1.32	0.990	1.31	0.983
1.00	1.34	1.340	1.32	1.320	1.32	1.320	1.31	1.310

Meter P–3
For Angles Right of Vertical Plane

Vs (m/s)	N0/Vs	No	N10/Vs	N10	N15/Vs	N15	N30/Vs	N30
0.05	1.13	0.057	1.20	0.060	1.15	0.058	1.19	0.060
0.10	1.25	0.125	1.27	0.127	1.25	0.125	1.27	0.127
0.15	1.28	0.192	1.29	0.194	1.29	0.194	1.30	0.195
0.20	1.30	0.260	1.30	0.260	1.30	0.260	1.30	0.260
0.25	1.30	0.325	1.32	0.330	1.32	0.330	1.32	0.330
0.30	1.31	0.393	1.32	0.396	1.32	0.396	1.32	0.396
0.35	1.32	0.462	1.32	0.462	1.32	0.462	1.32	0.462
0.40	1.32	0.528	1.33	0.532	1.33	0.532	1.33	0.532
0.45	1.33	0.599	1.33	0.599	1.33	0.599	1.33	0.599
0.50	1.33	0.665	1.33	0.665	1.33	0.665	1.33	0.665
0.75	1.34	1.005	1.34	1.005	1.34	1.005	1.32	0.990
1.00	1.34	1.340	1.35	1.350	1.35	1.350	1.31	1.310

Meter P–4
For Angles Left of Vertical Plane

Vs (m/s)	N0/Vs	N0	N10/Vs	N10	N15/Vs	N15	N30/Vs	N30
0.05	1.25	0.063	1.11	0.056	1.11	0.056	1.19	0.060
0.10	1.31	0.131	1.25	0.125	1.25	0.125	1.27	0.127
0.15	1.35	0.203	1.29	0.194	1.29	0.194	1.30	0.195
0.20	1.35	0.270	1.31	0.262	1.31	0.262	1.33	0.266
0.25	1.36	0.340	1.33	0.333	1.33	0.333	1.34	0.335
0.30	1.36	0.408	1.34	0.402	1.34	0.402	1.34	0.402
0.35	1.36	0.476	1.35	0.473	1.35	0.473	1.35	0.473
0.40	1.36	0.544	1.35	0.540	1.35	0.540	1.35	0.540
0.45	1.37	0.617	1.36	0.612	1.36	0.612	1.36	0.612
0.50	1.37	0.685	1.36	0.680	1.36	0.680	1.36	0.680
0.75	1.37	1.028	1.35	1.013	1.35	1.013	1.35	1.013
1.00	1.37	1.370	1.36	1.360	1.36	1.360	1.36	1.360

Meter P–4
For Angles Right of Vertical Plane

Vs (m/s)	N0/Vs	N0	N10/Vs	N10	N15/Vs	N15	N30/Vs	N30
0.05	1.25	0.063	1.26	0.063	1.26	0.063	1.15	0.058
0.10	1.31	0.131	1.33	0.133	1.33	0.133	1.28	0.128
0.15	1.35	0.203	1.34	0.201	1.34	0.201	1.31	0.197
0.20	1.35	0.270	1.34	0.268	1.34	0.268	1.32	0.264
0.25	1.36	0.340	1.35	0.338	1.35	0.338	1.33	0.333
0.30	1.36	0.408	1.35	0.405	1.35	0.405	1.33	0.399
0.35	1.36	0.476	1.36	0.476	1.36	0.476	1.33	0.466
0.40	1.36	0.544	1.36	0.544	1.36	0.544	1.33	0.532
0.45	1.37	0.617	1.37	0.617	1.37	0.617	1.33	0.599
0.50	1.37	0.685	1.37	0.685	1.37	0.685	1.33	0.665
0.75	1.37	1.028	1.37	1.028	1.36	1.020	1.33	0.998
1.00	1.37	1.370	1.37	1.370	1.35	1.350	1.33	1.330

Appendix C - Calibration equations

Standard Calibration for 1–179

Vx (m/s)	N0/Vx	N0	Vx using model; Vmod	$\frac{Vmod-Vx}{Vx}$ (%)
0.05	1.32	0.066	0.0532	6.37
0.10	1.38	0.138	0.1009	0.91
0.15	1.41	0.212	0.1496	−0.24
0.20	1.43	0.286	0.1990	−0.49
0.25	1.44	0.360	0.2481	−0.77
0.30	1.45	0.435	0.2978	−0.74
0.35	1.46	0.511	0.3482	−0.52
0.40	1.47	0.588	0.3992	−0.20
0.45	1.48	0.666	0.4509	0.21
0.50	1.48	0.740	0.5000	−0.00
0.75	1.49	1.118	0.7502	0.03
1.00	1.50	1.500	1.0038	0.38
1.50	1.50	2.250	1.5010	0.06
2.00	1.50	3.000	1.9981	−0.09

Standard Calibration
Equations for 1–179

Regression Output:	Vx=a+b*N0
Constant	0.009431
Std Err of Y Est	0.001919
R Squared	0.999989
No. of Observations	14
Degrees of Freedom	12
X Coefficient(s)	0.6629
Std Err of Coef.	0.00062

Regression Output:	N0=a+b*Vx
Constant	−0.01422
Std Err of Y Est	0.002895
R Squared	0.999989
No. of Observations	14
Degrees of Freedom	12
X Coefficient(s)	1.508506
Std Err of Coef.	0.001412

Meter 1–179
For 5 Degrees Below Horizontal Plane

Vx = Vs*Cos 5 (m/s)	N5	N ^ 0.993	Vx using model; Vmod	(Vmod–Vx)/Vx (%)
0.0498	0.064			
0.0996	0.135	0.137	0.1004	0.79
0.1494	0.206	0.208	0.1482	−0.84
0.1992	0.278	0.281	0.1972	−1.03
0.2490	0.355	0.358	0.2491	0.03
0.2989	0.429	0.432	0.2990	0.04
0.3487	0.500	0.503	0.3471	−0.46
0.3985	0.576	0.578	0.3978	−0.17
0.4483	0.648	0.650	0.4462	−0.47
0.4981	0.725	0.727	0.4978	−0.06
0.7471	1.103	1.102	0.7506	0.46
0.9962	1.480	1.476	1.0028	0.66
1.4943	2.220	2.208	1.4959	0.10
1.9924	2.960	2.938	1.9878	−0.23

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Regression Output: Vx = a + b*N5 ^ 0.993

Constant	0.008152
Std Err of Y Est	0.002909
R Squared	0.999976
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.673887
Std Err of Coef.	0.000995

Regression Output: N5 ^ 0.993 = a + b*Vx

Constant	−0.01208
Std Err of Y Est	0.004317
R Squared	0.999976
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	1.483893
Std Err of Coef.	0.002192

Meter 1–179
For 10 Degrees Below Horizontal Plane

Vx = Vs*Cos 10 (m/s)	N10		Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492				
0.0985	0.137		0.0984	−0.11
0.1477	0.210		0.1471	−0.45
0.1970	0.284		0.1964	−0.29
0.2462	0.358		0.2454	−0.32
0.2954	0.432		0.2951	−0.12
0.3447	0.504		0.3431	−0.46
0.3939	0.580		0.3938	−0.04
0.4432	0.653		0.4421	−0.24
0.4924	0.730		0.4938	0.28
0.7386	1.103		0.7422	0.48
0.9848	1.470		0.9872	0.25
1.4772	2.205		1.4772	0.01
1.9696	2.940		1.9674	−0.11

Regression Output:		Vx=a+b*N10
Constant		0.007021
Std Err of Y Est		0.001635
R Squared		0.999992
No. of Observations		13
Degrees of Freedom		11
X Coefficient(s)	0.666808	
Std Err of Coef.	0.00057	

Regression Output:		N10 =a+b*Vx
Constant		−0.01052
Std Err of Y Est		0.002497
R Squared		0.999992
No. of Observations		13
Degrees of Freedom		11
X Coefficient(s)	1.49967	
Std Err of Coef.	0.001282	

Meter 1–179
For 15 Degrees Below Horizontal Plane

Vx = Vs*Cos 15 (m/s)	N15		Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483				
0.0966	0.133		0.0964	−0.17
0.1449	0.206		0.1441	−0.54
0.1932	0.278		0.1918	−0.73
0.2415	0.353		0.2408	−0.30
0.2898	0.426		0.2891	−0.23
0.3381	0.500		0.3381	0.00
0.3864	0.572		0.3851	−0.33
0.4347	0.648		0.4351	0.10
0.4830	0.720		0.4824	−0.11
0.7244	1.095		0.7290	0.63
0.9659	1.460		0.9690	0.32
1.4489	2.190		1.4491	0.01
1.9319	2.920		1.9291	−0.14

Regression Output:		Vx=a+b*N15
Constant		0.008968
Std Err of Y Est		0.001997
R Squared		0.999988
No. of Observations		13
Degrees of Freedom		11
X Coefficient(s)	0.657585	
Std Err of Coef.	0.000687	

Regression Output:		N15=a+b*Vx
Constant		−0.01363
Std Err of Y Est		0.003036
R Squared		0.999988
No. of Observations		13
Degrees of Freedom		11
X Coefficient(s)	1.520697	
Std Err of Coef.	0.00159	

Meter 1–179
For 5 Degrees Above Horizontal Plane

Vx = Vs*Cos 5 (m/s)	N5	N5 ^ 0.995	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0498				
0.0996	0.133	0.134	0.1005	0.91
0.1494	0.204	0.206	0.1487	−0.47
0.1992	0.276	0.278	0.1975	−0.86
0.2490	0.348	0.349	0.2459	−1.25
0.2989	0.423	0.425	0.2970	−0.63
0.3487	0.497	0.499	0.3470	−0.49
0.3985	0.572	0.574	0.3976	−0.22
0.4483	0.648	0.649	0.4489	0.13
0.4981	0.720	0.721	0.4974	−0.14
0.7471	1.103	1.102	0.7549	1.04
0.9962	1.470	1.467	1.0019	0.58
1.4943	2.205	2.196	1.4950	0.05
1.9924	2.940	2.924	1.9873	−0.25

Regression Output:	Vx=a+b*N5 ^ 0.995
Constant	0.009659
Std Err of Y Est	0.003589
R Squared	0.999963
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.676312
Std Err of Coef.	0.001232

Regression Output:	N5 ^ 0.995=a+b*Vx
Constant	−0.01425
Std Err of Y Est	0.005307
R Squared	0.999963
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	1.478554
Std Err of Coef.	0.002694

Meter 1–179
For 10 Degrees Above Horizontal Plane

Vx = Vs*Cos 10 (m/s)	N10		Vx using model; Vmod	$\frac{Vmod-Vx}{Vx}$ (%)
0.0492				
0.0985	0.130		0.1004	1.98
0.1477	0.200		0.1491	0.93
0.1970	0.268		0.1971	0.05
0.2462	0.338		0.2457	−0.19
0.2954	0.408		0.2951	−0.12
0.3447	0.480		0.3452	0.14
0.3939	0.548		0.3931	−0.20
0.4432	0.621		0.4442	0.24
0.4924	0.690		0.4926	0.03
0.7386	1.035		0.7341	−0.61
0.9848	1.390		0.9827	−0.21
1.4772	2.100		1.4799	0.18
1.9696	2.800		1.9700	0.02

Regression Output:		Vx=a+b*N10
Constant		0.009401
Std Err of Y Est		0.001901
R Squared		0.99999
No. of Observations		13
Degrees of Freedom		11
X Coefficient(s)	0.700225	
Std Err of Coef.	0.000683	

Regression Output:		N10=a+b*Vx
Constant		−0.01342
Std Err of Y Est		0.002714
R Squared		0.99999
No. of Observations		13
Degrees of Freedom		11
X Coefficient(s)	1.428098	
Std Err of Coef.	0.001394	

Meter 1–179
For 15 Degrees Above Horizontal Plane

Vx = Vs*Cos 15 (m/s)	N15	N15^.935	Vx using model; Vmod	(Vmod–Vx)/Vx (%)
0.0483				
0.0966	0.130	0.148	0.0954	−1.21
0.1449	0.194	0.215	0.1466	1.20
0.1932	0.256	0.280	0.1960	1.44
0.2415	0.320	0.345	0.2457	1.73
0.2898	0.381	0.406	0.2924	0.91
0.3381	0.445	0.469	0.3406	0.74
0.3864	0.504	0.527	0.3853	−0.27
0.4347	0.567	0.588	0.4323	−0.55
0.4830	0.630	0.649	0.4789	−0.83
0.7244	0.960	0.963	0.7189	−0.76
0.9659	1.300	1.278	0.9605	−0.56
1.4489	2.010	1.921	1.4528	0.27
1.9319	2.720	2.549	1.9337	0.09

Regression Output: Vx=a+b*N15^0.935

Constant	−0.01825
Std Err of Y Est	0.003623
R Squared	0.99996
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.765849
Std Err of Coef.	0.001452

Regression Output: N15^0.935=a+b*Vx

Constant	0.023867
Std Err of Y Est	0.00473
R Squared	0.99996
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	1.305689
Std Err of Coef.	0.002476

Standard Calibration for P–1

Vx (m/s)	N0	N0 ^ 1.004	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.05	0.056			
0.10	0.118	0.117	0.1010	0.99
0.15	0.185	0.183	0.1491	−0.62
0.20	0.252	0.251	0.1979	−1.03
0.25	0.320	0.319	0.2472	−1.11
0.30	0.390	0.389	0.2980	−0.66
0.35	0.462	0.461	0.3503	0.08
0.40	0.532	0.531	0.4011	0.28
0.45	0.603	0.602	0.4527	0.61
0.50	0.675	0.674	0.5051	1.02
0.75	1.013	1.013	0.7508	0.10
1.00	1.350	1.352	0.9968	−0.32

Standard Calibration
Equations for P–1

Regression Output:		Vx=a+b*N0 ^ 1.004
Constant		0.016102
Std Err of Y Est		0.002653
R Squared		0.999912
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	0.725561	
Std Err of Coef.	0.002265	

Regression Output:		N0 ^ 1.004=a+b*Vx
Constant		−0.02214
Std Err of Y Est		0.003657
R Squared		0.999912
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	1.378123	
Std Err of Coef.	0.004303	

Meter F-1
For 5 Degrees Below Horizontal Plane

Vx = Vs*Cos 5 (m/s)	N5		Vx using model; Vmod	Vmod−Vx / Vx (%)
0.0498	0.054		0.0465	−6.67
0.0996	0.123		0.0989	−0.73
0.1494	0.191		0.1498	0.24
0.1992	0.256		0.1992	−0.03
0.2490	0.323		0.2493	0.11
0.2989	0.390		0.3002	0.45
0.3487	0.455		0.3492	0.16
0.3985	0.520		0.3982	−0.06
0.4483	0.590		0.4506	0.52
0.4981	0.655		0.5000	0.39
0.7471	0.983		0.7470	−0.02
0.9962	1.310		0.9939	−0.23

Regression Output:		Vx=a+b*N5
Constant		0.00615
Std Err of Y Est		0.001688
R Squared		0.999966
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.754007	
Std Err of Coef.	0.001396	

Regression Output:		N5=a+b*Vx
Constant		−0.00814
Std Err of Y Est		0.002239
R Squared		0.999966
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.326202	
Std Err of Coef.	0.002456	

Meter P–1
For 10 Degrees Below Horizontal Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 1.009	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.040			
0.0985	0.110	0.108	0.0978	−0.70
0.1477	0.176	0.173	0.1487	0.63
0.1970	0.238	0.235	0.1974	0.20
0.2462	0.300	0.297	0.2458	−0.17
0.2954	0.363	0.360	0.2951	−0.12
0.3447	0.427	0.424	0.3452	0.16
0.3939	0.488	0.485	0.3931	−0.21
0.4432	0.554	0.551	0.4446	0.32
0.4924	0.615	0.612	0.4929	0.11
0.7386	0.923	0.922	0.7354	−0.44
0.9848	1.240	1.242	0.9865	0.17

Regression Output:		Vx=a+b*N10 ^ 1.009
Constant		0.013319
Std Err of Y Est		0.001424
R Squared		0.999974
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	0.783303	
Std Err of Coef.	0.001333	

Regression Output:		N10 ^ 1.009=a+b*Vx
Constant		−0.01699
Std Err of Y Est		0.001818
R Squared		0.999974
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	1.276612	
Std Err of Coef.	0.002172	

Meter P–1
For 15 Degrees Below Horizontal Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.006	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483				
0.0966	0.107	0.106	0.0962	−0.43
0.1449	0.165	0.163	0.1450	0.10
0.1932	0.222	0.220	0.1932	−0.01
0.2415	0.278	0.275	0.2401	−0.58
0.2898	0.336	0.334	0.2896	−0.06
0.3381	0.392	0.390	0.3371	−0.30
0.3864	0.452	0.450	0.3880	0.41
0.4347	0.509	0.506	0.4359	0.29
0.4830	0.565	0.563	0.4839	0.20
0.7244	0.848	0.847	0.7243	−0.02
0.9659	1.130	1.131	0.9651	−0.08

Regression Output: Vx=a+b*N15 ^ 1.006

Constant	0.006696
Std Err of Y Est	0.000994
R Squared	0.999987
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.847551
Std Err of Coef.	0.001026

Regression Output: N15 ^ 1.006=a+b*Vx

Constant	−0.00789
Std Err of Y Est	0.001173
R Squared	0.999987
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.179854
Std Err of Coef.	0.001429

Meter P–1
For 5 Degrees Above Horizontal Plane

Vx = Vs*Cos 5 (m/s)	N5	N ^ 1.012	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0498	0.051	0.049	0.0502	0.74
0.0996	0.116	0.113	0.0986	−1.00
0.1494	0.183	0.179	0.1489	−0.34
0.1992	0.248	0.244	0.1979	−0.66
0.2490	0.315	0.311	0.2486	−0.18
0.2989	0.381	0.377	0.2987	−0.06
0.3487	0.448	0.444	0.3496	0.26
0.3985	0.512	0.508	0.3983	−0.04
0.4483	0.581	0.577	0.4505	0.50
0.4981	0.645	0.642	0.4998	0.34
0.7471	0.968	0.967	0.7468	−0.04
0.9962	1.290	1.294	0.9949	−0.13

Regression Output: Vx=a+b*N5 ^ 1.012

Constant	0.01283
Std Err of Y Est	0.001181
R Squared	0.999983
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.758958
Std Err of Coef.	0.000984

Regression Output: N5 ^ 1.012=a+b*Vx

Constant	−0.0169
Std Err of Y Est	0.001557
R Squared	0.999983
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.317575
Std Err of Coef.	0.001707

Meter P–1
For 10 Degrees Above Horizontal Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 1.009	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.031	0.030	0.0401	−18.59
0.0985	0.107	0.105	0.0991	0.62
0.1477	0.170	0.167	0.1479	0.15
0.1970	0.232	0.229	0.1970	0.00
0.2462	0.295	0.292	0.2465	0.12
0.2954	0.360	0.357	0.2977	0.76
0.3447	0.424	0.420	0.3478	0.90
0.3939	0.484	0.481	0.3956	0.43
0.4432	0.549	0.546	0.4470	0.87
0.4924	0.610	0.607	0.4953	0.59
0.7386	0.915	0.914	0.7374	−0.16
0.9848	1.220	1.222	0.9802	−0.47

Regression Output: Vx=a+b*N10 ^ 1.009

Constant	0.016394
Std Err of Y Est	0.003842
R Squared	0.999818
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.788616
Std Err of Coef.	0.003362

Regression Output: N10 ^ 1.009=a+b*Vx

Constant	−0.0207
Std Err of Y Est	0.004871
R Squared	0.999818
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.267814
Std Err of Coef.	0.005405

Meter P–1
For 15 Degrees Above Horizontal Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.029	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483	0.026			
0.0966	0.095	0.089	0.0957	−0.97
0.1449	0.153	0.145	0.1444	−0.31
0.1932	0.214	0.205	0.1963	1.64
0.2415	0.270	0.260	0.2444	1.20
0.2898	0.324	0.314	0.2910	0.42
0.3381	0.378	0.367	0.3378	−0.08
0.3864	0.432	0.422	0.3848	−0.40
0.4347	0.486	0.476	0.4320	−0.61
0.4830	0.540	0.530	0.4794	−0.74
0.7244	0.818	0.813	0.7246	0.02
0.9659	1.090	1.093	0.9679	0.20

Regression Output:	Vx=a+b*N15 ^ 1.029
Constant	0.018568
Std Err of Y Est	0.002285
R Squared	0.99993
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.868742
Std Err of Coef.	0.002418

Regression Output:	N15 ^ 1.029=a+b*Vx
Constant	−0.02134
Std Err of Y Est	0.00263
R Squared	0.99993
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.151009
Std Err of Coef.	0.003204

Standard Calibration for P−3

Vx (m/s)	N0	Vx using model; Vmod	Vmod−Vx / Vx (%)
0.05	0.057	0.0501	0.22
0.10	0.125	0.1008	0.77
0.15	0.192	0.1503	0.21
0.20	0.260	0.2006	0.30
0.25	0.325	0.2487	−0.53
0.30	0.393	0.2990	−0.35
0.35	0.462	0.3500	−0.01
0.40	0.528	0.3988	−0.30
0.45	0.599	0.4509	0.21
0.50	0.665	0.5001	0.02
0.75	1.005	0.7515	0.20
1.00	1.340	0.9993	−0.07

Standard Calibration Equations for P−3

Regression Output:		Vx=a+b*N0
Constant		0.008328
Std Err of Y Est		0.000956
R Squared		0.999989
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.739506	
Std Err of Coef.	0.000773	

Regression Output:		N0=a+b*Vx
Constant		−0.01126
Std Err of Y Est		0.001293
R Squared		0.999989
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.352239	
Std Err of Coef.	0.001413	

Meter P–3
For 5 Degrees Below Horizontal Plane

Vx = Vs*Cos 5 (m/s)	N5		Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0498	0.058		0.0487	–2.29
0.0996	0.127		0.1000	0.37
0.1494	0.195		0.1502	0.52
0.1992	0.262		0.1997	0.22
0.2490	0.330		0.2499	0.34
0.2989	0.396		0.2986	–0.08
0.3487	0.462		0.3474	–0.38
0.3985	0.532		0.3990	0.14
0.4483	0.599		0.4482	–0.03
0.4981	0.665		0.4973	–0.17
0.7471	1.005		0.7483	0.16
0.9962	1.340		0.9957	–0.05

Regression Output:		Vx=a+b*N5
Constant		0.006208
Std Err of Y Est		0.000859
R Squared		0.999991
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.738418	
Std Err of Coef.	0.000696	

Regression Output:		N5=a+b*Vx
Constant		–0.0084
Std Err of Y Est		0.001163
R Squared		0.999991
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.354234	
Std Err of Coef.	0.001276	

Meter P–3
For 10 Degrees Below Horizontal Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 1.005	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492				
0.0985	0.118	0.117	0.0975	−0.97
0.1477	0.186	0.184	0.1491	0.93
0.1970	0.250	0.248	0.1977	0.38
0.2462	0.315	0.313	0.2472	0.39
0.2954	0.378	0.376	0.2951	−0.11
0.3447	0.441	0.439	0.3431	−0.45
0.3939	0.508	0.506	0.3942	0.08
0.4432	0.572	0.570	0.4427	−0.10
0.4924	0.635	0.634	0.4912	−0.25
0.7386	0.960	0.960	0.7397	0.15
0.9848	1.280	1.282	0.9848	−0.00

Regression Output:		Vx=a+b*N10 ^ 1.003
Constant		0.008599
Std Err of Y Est		0.001039
R Squared		0.999986
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	0.761717	
Std Err of Coef.	0.000945	

Regression Output:		N10 ^ 1.003=a+b*Vx
Constant		−0.01128
Std Err of Y Est		0.001363
R Squared		0.999986
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	1.312806	
Std Err of Coef.	0.001629	

Meter P–3
For 15 Degrees Below Horizontal Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.025	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483				
0.0966	0.108	0.102	0.0958	−0.84
0.1449	0.173	0.165	0.1455	0.40
0.1932	0.236	0.228	0.1948	0.86
0.2415	0.298	0.289	0.2430	0.63
0.2898	0.357	0.348	0.2898	0.02
0.3381	0.417	0.407	0.3368	−0.36
0.3864	0.476	0.467	0.3840	−0.60
0.4347	0.540	0.532	0.4350	0.07
0.4830	0.600	0.592	0.4828	−0.03
0.7244	0.900	0.898	0.7239	−0.08
0.9659	1.200	1.205	0.9669	0.10

Regression Output*: Vx=a+b*N15 ^ 1.025

Constant	0.01512
Std Err of Y Est	0.001267
R Squared	0.999979
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.789559
Std Err of Coef.	0.001219

Regression Output: N15 ^ 1.025=a+b*Vx

Constant	−0.01914
Std Err of Y Est	0.001605
R Squared	0.999979
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.266503
Std Err of Coef.	0.001955

Meter P–3
For 5 Degrees Above Horizontal Plane

Vx = Vs*Cos 5 (m/s)	N5	N ^ 0.985	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0498	0.057	0.059	0.0500	0.39
0.0996	0.120	0.124	0.0987	−0.88
0.1494	0.185	0.189	0.1478	−1.07
0.1992	0.252	0.257	0.1989	−0.16
0.2490	0.318	0.323	0.2483	−0.30
0.2989	0.384	0.390	0.2983	−0.19
0.3487	0.452	0.457	0.3489	0.06
0.3985	0.520	0.525	0.4001	0.41
0.4483	0.585	0.590	0.4486	0.08
0.4981	0.655	0.659	0.5008	0.54
0.7471	0.990	0.990	0.7494	0.30
0.9962	1.320	1.315	0.9930	−0.32

Regression Output:		Vx=a+b*N5 ^ 0.985
Constant		0.005698
Std Err of Y Est		0.00172
R Squared		0.999964
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.751077	
Std Err of Coef.	0.001417	

Regression Output:		N5 ^ 0.985=a+b*Vx
Constant		−0.00757
Std Err of Y Est		0.00229
R Squared		0.999964
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.331375	
Std Err of Coef.	0.002512	

Meter P–3
For 10 Degrees Above Horizontal Plane

Vx = Vs*Cos 10 (m/s)	N10	N^1.015	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492				
0.0985	0.110	0.106	0.0978	−0.69
0.1477	0.177	0.172	0.1489	0.77
0.1970	0.240	0.235	0.1971	0.09
0.2462	0.305	0.300	0.2471	0.38
0.2954	0.369	0.364	0.2965	0.37
0.3447	0.431	0.425	0.3441	−0.16
0.3939	0.492	0.487	0.3918	−0.53
0.4432	0.558	0.553	0.4431	−0.01
0.4924	0.620	0.616	0.4914	−0.21
0.7386	0.938	0.937	0.7395	0.12
0.9848	1.250	1.254	0.9850	0.02

Regression Output: Vx=a+b*N10^1.015

Constant	0.015544
Std Err of Y Est	0.00108
R Squared	0.999985
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.772976
Std Err of Coef.	0.000997

Regression Output: N10^1.015=a+b*Vx

Constant	−0.0201
Std Err of Y Est	0.001397
R Squared	0.999985
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.293682
Std Err of Coef.	0.001669

Meter P–3
For 15 Degrees Above Horizontal Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.035	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483				
0.0966	0.092	0.085	0.0974	0.88
0.1449	0.155	0.145	0.1454	0.38
0.1932	0.216	0.205	0.1934	0.09
0.2415	0.280	0.268	0.2438	0.94
0.2898	0.339	0.326	0.2906	0.27
0.3381	0.399	0.386	0.3385	0.12
0.3864	0.456	0.444	0.3842	−0.56
0.4347	0.518	0.506	0.4338	−0.20
0.4830	0.575	0.564	0.4803	−0.54
0.7244	0.870	0.866	0.7214	−0.42
0.9659	1.170	1.176	0.9696	0.38

Regression Output:	Vx=a+b*N15 ^ 1.035
Constant	0.029837
Std Err of Y Est	0.002157
R Squared	0.999938
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.798801
Std Err of Coef.	0.002099

Regression Output:	N15 ^ 1.035=a+b*Vx
Constant	−0.03732
Std Err of Y Est	0.0027
R Squared	0.999938
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.251798
Std Err of Coef.	0.003289

Standard Calibration for P−4

Vx (m/s)	N0	N0 ^ 1.005	Vx using model; Vmod	(Vmod−Vx)/Vx (%)
0.05	0.063	0.062	0.0501	0.19
0.10	0.131	0.130	0.0994	−0.60
0.15	0.203	0.201	0.1510	0.67
0.20	0.270	0.268	0.1998	−0.10
0.25	0.340	0.338	0.2505	0.19
0.30	0.408	0.406	0.2998	−0.08
0.35	0.476	0.474	0.3491	−0.26
0.40	0.544	0.542	0.3984	−0.39
0.45	0.617	0.615	0.4511	0.25
0.50	0.685	0.684	0.5009	0.18
0.75	1.028	1.028	0.7501	0.02
1.00	1.370	1.372	0.9998	−0.02

Standard Calibration
Equations for P−4

Regression Output:	Vx=a+b*N0 ^ 1.005
Constant	0.005424
Std Err of Y Est	0.000837
R Squared	0.999992
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.724672
Std Err of Coef.	0.000663

Regression Output:	N0 ^ 1.005=a+b*Vx
Constant	−0.00748
Std Err of Y Est	0.001156
R Squared	0.999992
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.379923
Std Err of Coef.	0.001263

Meter P–4
For 5 Degrees Below Horizontal Plane

Vx = Vs*Cos 5 (m/s)	N5	N ^ 1.032	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0498	0.062			
0.0996	0.130	0.122	0.0990	−0.58
0.1494	0.203	0.192	0.1502	0.52
0.1992	0.272	0.261	0.1998	0.28
0.2490	0.340	0.328	0.2487	−0.12
0.2989	0.408	0.396	0.2980	−0.29
0.3487	0.480	0.468	0.3501	0.40
0.3985	0.548	0.538	0.4002	0.43
0.4483	0.612	0.602	0.4472	−0.24
0.4981	0.680	0.672	0.4973	−0.16
0.7471	1.013	1.013	0.7445	−0.36
0.9962	1.350	1.363	0.9981	0.19

Regression Output:		Vx=a+b*N5 ^ 1.032
Constant		0.010839
Std Err of Y Est		0.001468
R Squared		0.999973
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	0.724284	
Std Err of Coef.	0.001256	

Regression Output:		N5 ^ 1.032=a+b*Vx
Constant		−0.01495
Std Err of Y Est		0.002027
R Squared		0.999973
No. of Observations		11
Degrees of Freedom		9
X Coefficient(s)	1.380637	
Std Err of Coef.	0.002394	

Meter P–4
For 10 Degrees Below Horizontal Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 1.032	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.055	0.050	0.0490	−0.54
0.0985	0.127	0.119	0.0985	0.06
0.1477	0.198	0.188	0.1484	0.43
0.1970	0.270	0.259	0.1995	1.27
0.2462	0.338	0.326	0.2478	0.65
0.2954	0.405	0.393	0.2964	0.34
0.3447	0.473	0.461	0.3453	0.19
0.3939	0.536	0.525	0.3915	−0.60
0.4432	0.603	0.593	0.4405	−0.60
0.4924	0.670	0.661	0.4896	−0.57
0.7386	1.005	1.005	0.7373	−0.17
0.9848	1.340	1.353	0.9878	0.30

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Regression Output:		Vx=a+b*N10 ^ 1.032
Constant		0.012848
Std Err of Y Est		0.002041
R Squared		0.999949
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.720765	
Std Err of Coef.	0.001632	

Regression Output:		N10 ^ 1.032=a+b*Vx
Constant		−0.0178
Std Err of Y Est		0.002832
R Squared		0.999949
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.387343	
Std Err of Coef.	0.003142	

Meter P–4
For 15 Degrees Below Horizontal Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.030	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483	0.033			
0.0966	0.116	0.109	0.0957	−0.94
0.1449	0.185	0.175	0.1462	0.93
0.1932	0.248	0.238	0.1936	0.22
0.2415	0.313	0.302	0.2421	0.26
0.2898	0.375	0.364	0.2894	−0.13
0.3381	0.441	0.430	0.3396	0.45
0.3864	0.504	0.494	0.3877	0.35
0.4347	0.563	0.553	0.4326	−0.48
0.4830	0.625	0.616	0.4807	−0.48
0.7244	0.938	0.936	0.7230	−0.20
0.9659	1.250	1.258	0.9678	0.19

Regression Output:	Vx=a+b*N15 ^ 1.030
Constant	0.013193
Std Err of Y Est	0.00159
R Squared	0.999966
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.75857
Std Err of Coef.	0.001469

Regression Output:	N15 ^ 1.030=a+b*Vx
Constant	−0.01737
Std Err of Y Est	0.002096
R Squared	0.999966
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.318225
Std Err of Coef.	0.002553

Meter P–4
For 5 Degrees Above Horizontal Plane

Vx = Vs*Cos 5 (m/s)	N5	N ^ 0.994	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0498	0.055	0.056	0.0496	–0.36
0.0996	0.122	0.124	0.0987	–0.96
0.1494	0.191	0.192	0.1486	–0.55
0.1992	0.258	0.260	0.1977	–0.76
0.2490	0.330	0.332	0.2500	0.40
0.2989	0.399	0.401	0.3001	0.41
0.3487	0.466	0.468	0.3483	–0.11
0.3985	0.536	0.538	0.3993	0.22
0.4483	0.603	0.605	0.4478	–0.10
0.4981	0.675	0.677	0.4999	0.36
0.7471	1.020	1.020	0.7489	0.24
0.9962	1.360	1.357	0.9939	–0.23

Regression Output: Vx=a+b*N5 ^ 0.994

Constant	0.009028
Std Err of Y Est	0.00139
R Squared	0.999977
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.725473
Std Err of Coef.	0.001106

Regression Output: N5 ^ 0.994=a+b*Vx

Constant	–0.01243
Std Err of Y Est	0.001916
R Squared	0.999977
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.378378
Std Err of Coef.	0.002101

Meter P–4
For 10 Degrees Above Horizontal Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 1.026	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.043	0.040	0.0490	−0.47
0.0985	0.113	0.107	0.0993	0.87
0.1477	0.180	0.172	0.1483	0.42
0.1970	0.246	0.237	0.1971	0.07
0.2462	0.310	0.301	0.2447	−0.61
0.2954	0.378	0.369	0.2956	0.04
0.3447	0.441	0.432	0.3429	−0.52
0.3939	0.508	0.499	0.3934	−0.13
0.4432	0.576	0.568	0.4449	0.39
0.4924	0.640	0.633	0.4935	0.22
0.7386	0.960	0.959	0.7381	−0.07
0.9848	1.280	1.288	0.9849	0.01

Regression Output: Vx=a+b*N10 ^ 1.026

Constant	0.019314
Std Err of Y Est	0.001065
R Squared	0.999986
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.749512
Std Err of Coef.	0.000885

Regression Output: N10 ^ 1.026=a+b*Vx

Constant	−0.02576
Std Err of Y Est	0.00142
R Squared	0.999986
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.334183
Std Err of Coef.	0.001576

Meter P–4
For 15 Degrees Above Horizontal Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.012	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483				
0.0966	0.100	0.097	0.0908	−6.01
0.1449	0.171	0.167	0.1462	0.89
0.1932	0.232	0.228	0.1940	0.42
0.2415	0.293	0.288	0.2416	0.04
0.2898	0.354	0.350	0.2901	0.10
0.3381	0.417	0.412	0.3395	0.41
0.3864	0.476	0.472	0.3865	0.05
0.4347	0.540	0.536	0.4373	0.60
0.4830	0.600	0.596	0.4849	0.40
0.7244	0.900	0.899	0.7238	−0.08
0.9659	1.200	1.203	0.9637	−0.23

Regression Output: Vx=a+b*N15 ^ 1.012

Constant	0.01396
Std Err of Y Est	0.002448
R Squared	0.99992
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.789752
Std Err of Coef.	0.002355

Regression Output: N15 ^ 1.012=a+b*Vx

Constant	−0.01764
Std Err of Y Est	0.003099
R Squared	0.99992
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.266119
Std Err of Coef.	0.003775

Standard Calibration for 1–061

Vx (m/s)	N0	N ^ 1.003	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.05	0.067			
0.10	0.137	0.136	0.1001	0.12
0.15	0.210	0.209	0.1489	−0.73
0.20	0.284	0.283	0.1984	−0.79
0.25	0.358	0.356	0.2476	−0.95
0.30	0.432	0.431	0.2975	−0.82
0.35	0.511	0.510	0.3505	0.14
0.40	0.584	0.583	0.3995	−0.13
0.45	0.662	0.661	0.4515	0.32
0.50	0.740	0.739	0.5041	0.83
0.75	1.110	1.110	0.7527	0.36
1.00	1.480	1.482	1.0015	0.15
1.50	2.220	2.225	1.4995	−0.03
2.00	2.960	2.970	1.9981	−0.09

Standard Calibration
Equations for 1–061

Regression Output:	Vx=a+b*N0 ^ 1.003
Constant	0.008894
Std Err of Y Est	0.002091
R Squared	0.999988
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.669859
Std Err of Coef.	0.000708

Regression Output:	N0 ^ 1.003=a+b*Vx
Constant	−0.01327
Std Err of Y Est	0.003121
R Squared	0.999988
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	1.492832
Std Err of Coef.	0.001578

Meter 1–061
For 10 Degrees Left of Vertical Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 1.016	Vx using model; Vmod	(Vmod–Vx)/Vx (%)
0.0492				
0.0985	0.127	0.123	0.0992	0.77
0.1477	0.200	0.194	0.1459	–1.23
0.1970	0.276	0.270	0.1954	–0.77
0.2462	0.353	0.347	0.2452	–0.40
0.2954	0.429	0.423	0.2952	–0.10
0.3447	0.504	0.499	0.3443	–0.13
0.3939	0.580	0.575	0.3941	0.05
0.4432	0.657	0.653	0.4448	0.36
0.4924	0.735	0.731	0.4962	0.76
0.7386	1.103	1.104	0.7393	0.10
0.9848	1.470	1.479	0.9839	–0.10
1.4772	2.205	2.233	1.4757	–0.11
1.9696	2.940	2.991	1.9701	0.03

Regression Output: Vx=a+b*N10 ^ 1.016

Constant	0.019093
Std Err of Y Est	0.001601
R Squared	0.999993
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.652267
Std Err of Coef.	0.000536

Regression Output: N10 ^ 1.016=a+b*Vx

Constant	–0.02927
Std Err of Y Est	0.002455
R Squared	0.999993
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	1.533103
Std Err of Coef.	0.001261

Meter 1–179
For 15 Degrees Left of Vertical Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.005	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483				
0.0966	0.138	0.137	0.0972	0.63
0.1449	0.209	0.207	0.1436	−0.91
0.1932	0.282	0.280	0.1920	−0.62
0.2415	0.355	0.353	0.2401	−0.56
0.2898	0.429	0.427	0.2890	−0.27
0.3381	0.504	0.502	0.3386	0.14
0.3864	0.576	0.574	0.3862	−0.05
0.4347	0.653	0.651	0.4368	0.49
0.4830	0.725	0.724	0.4848	0.38
0.7244	1.088	1.088	0.7252	0.10
0.9659	1.450	1.453	0.9659	−0.00
1.4489	2.175	2.183	1.4483	−0.04
1.9319	2.900	2.915	1.9315	−0.02

Regression Output:	Vx=a+b*N15 ^ 1.005
Constant	0.007008
Std Err of Y Est	0.001177
R Squared	0.999996
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.660098
Std Err of Coef.	0.000407

Regression Output:	N15 ^ 1.005=a+b*Vx
Constant	−0.01061
Std Err of Y Est	0.001783
R Squared	0.999996
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	1.514921
Std Err of Coef.	0.000933

Meter 1–179
For 30 Degrees Left of Vertical Plane

Vx = Vs*Cos 30 (m/s)	N30	N ^ 0.999	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0433				
0.0866	0.133	0.133	0.0871	0.56
0.1299	0.203	0.203	0.1290	−0.68
0.1732	0.272	0.272	0.1710	−1.30
0.2165	0.345	0.345	0.2150	−0.71
0.2598	0.417	0.417	0.2584	−0.55
0.3031	0.490	0.490	0.3024	−0.23
0.3464	0.564	0.564	0.3470	0.17
0.3897	0.635	0.635	0.3895	−0.06
0.4330	0.710	0.710	0.4350	0.46
0.6495	1.073	1.072	0.6534	0.59
0.8660	1.430	1.429	0.8687	0.31
1.2990	2.145	2.143	1.2991	0.01
1.7321	2.860	2.857	1.7294	−0.15

Regression Output: Vx=a+b*N30 ^ 0.999

Constant	0.006729
Std Err of Y Est	0.002
R Squared	0.999985
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.602978
Std Err of Coef.	0.000704

Regression Output: N30 ^ 0.999=a+b*Vx

Constant	−0.01115
Std Err of Y Est	0.003317
R Squared	0.999985
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	1.658411
Std Err of Coef.	0.001937

Meter 1–061
For 10 Degrees Right of Vertical Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 1.022	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.067			
0.0985	0.136	0.130	0.0994	0.93
0.1477	0.212	0.204	0.1474	−0.25
0.1970	0.286	0.278	0.1951	−0.97
0.2462	0.365	0.357	0.2459	−0.10
0.2954	0.444	0.436	0.2971	0.55
0.3447	0.522	0.514	0.3474	0.80
0.3939	0.596	0.589	0.3960	0.53
0.4432	0.671	0.665	0.4447	0.35
0.4924	0.745	0.740	0.4935	0.23
0.7386	1.110	1.113	0.7341	−0.61
0.9848	1.480	1.493	0.9798	−0.51
1.4772	2.220	2.259	1.4750	−0.15
1.9696	2.960	3.032	1.9739	0.22

Regression Output: Vx=a+b*N10 ^ 1.022

Constant	0.015299
Std Err of Y Est	0.002889
R Squared	0.999976
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.646078
Std Err of Coef.	0.000958

Regression Output: N10 ^ 1.022=a+b*Vx

Constant	−0.02366
Std Err of Y Est	0.004472
R Squared	0.999976
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	1.547764
Std Err of Coef.	0.002296

Meter 1–179
For 15 Degrees Right of Vertical Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.005	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483	0.066	0.065	0.0526	8.81
0.0966	0.135	0.134	0.0968	0.20
0.1449	0.209	0.207	0.1440	−0.59
0.1932	0.284	0.282	0.1927	−0.27
0.2415	0.358	0.356	0.2401	−0.59
0.2898	0.432	0.430	0.2882	−0.56
0.3381	0.508	0.506	0.3369	−0.34
0.3864	0.580	0.578	0.3838	−0.66
0.4347	0.657	0.656	0.4336	−0.24
0.4830	0.735	0.734	0.4841	0.24
0.7244	1.110	1.111	0.7272	0.38
0.9659	1.480	1.483	0.9675	0.16
1.4489	2.220	2.229	1.4489	−0.00
1.9319	2.960	2.976	1.9311	−0.04

Regression Output:		Vx=a+b*N15 ^ 1.005
Constant		0.010536
Std Err of Y Est		0.001934
R Squared		0.999989
No. of Observations		14
Degrees of Freedom		12
X Coefficient(s)	0.645328	
Std Err of Coef.	0.00063	

Regression Output:		N15 ^ 1.005=a+b*Vx
Constant		−0.01632
Std Err of Y Est		0.002997
R Squared		0.999989
No. of Observations		14
Degrees of Freedom		12
X Coefficient(s)	1.549582	
Std Err of Coef.	0.001513	

Meter 1–179
For 30 Degrees Right of Vertical Plane

Vx = Vs*Cos 30 (m/s)	N30	N ^ 1.001	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0433	0.063	0.062	0.0460	6.33
0.0866	0.129	0.129	0.0875	1.00
0.1299	0.197	0.196	0.1295	−0.29
0.1732	0.264	0.264	0.1716	−0.92
0.2165	0.333	0.332	0.2143	−1.00
0.2598	0.402	0.402	0.2577	−0.82
0.3031	0.473	0.472	0.3017	−0.48
0.3464	0.544	0.544	0.3463	−0.04
0.3897	0.612	0.612	0.3887	−0.26
0.4330	0.685	0.685	0.4343	0.29
0.6495	1.035	1.035	0.6528	0.50
0.8660	1.380	1.380	0.8682	0.25
1.2990	2.070	2.072	1.2992	0.02
1.7321	2.760	2.763	1.7304	−0.09

Regression Output:		Vx=a+b*N30 ^ 1.001
Constant		0.007167
Std Err of Y Est		0.001888
R Squared		0.999986
No. of Observations		14
Degrees of Freedom		12
X Coefficient(s)	0.623741	
Std Err of Coef.	0.000663	

Regression Output:		N30 ^ 1.001=a+b*Vx
Constant		−0.01148
Std Err of Y Est		0.003026
R Squared		0.999986
No. of Observations		14
Degrees of Freedom		12
X Coefficient(s)	1.603209	
Std Err of Coef.	0.001704	

Meter P–1
For 10 Degrees Left of Vertical Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 0.995	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.057	0.057	0.0495	0.52
0.0985	0.121	0.122	0.0976	−0.84
0.1477	0.188	0.189	0.1472	−0.38
0.1970	0.254	0.256	0.1966	−0.20
0.2462	0.323	0.324	0.2474	0.49
0.2954	0.390	0.392	0.2975	0.68
0.3447	0.455	0.457	0.3456	0.27
0.3939	0.520	0.522	0.3937	−0.05
0.4432	0.585	0.587	0.4418	−0.31
0.4924	0.650	0.651	0.4898	−0.52
0.7386	0.990	0.990	0.7409	0.31
0.9848	1.320	1.318	0.9841	−0.07

Regression Output: Vx=a+b*N10 ^ 0.995

Constant	0.007009
Std Err of Y Est	0.001472
R Squared	0.999973
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.741233
Std Err of Coef.	0.001211

Regression Output: N10 ^ 0.995=a+b*Vx

Constant	−0.00944
Std Err of Y Est	0.001986
R Squared	0.999973
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.349067
Std Err of Coef.	0.002203

Meter P−1
For 15 Degrees Left of Vertical Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 0.985	Vx using model; Vmod	Vmod−Vx / Vx (%)
0.0483	0.055	0.057	0.0485	0.48
0.0966	0.118	0.122	0.0958	−0.83
0.1449	0.185	0.189	0.1449	−0.02
0.1932	0.250	0.255	0.1929	−0.13
0.2415	0.320	0.326	0.2441	1.08
0.2898	0.384	0.390	0.2907	0.32
0.3381	0.448	0.453	0.3372	−0.25
0.3864	0.512	0.517	0.3836	−0.71
0.4347	0.581	0.585	0.4332	−0.33
0.4830	0.650	0.654	0.4834	0.10
0.7244	0.990	0.990	0.7280	0.49
0.9659	1.320	1.315	0.9642	−0.18

Regression Output: Vx=a+b*N15 ^ 0.985

Constant	0.007077
Std Err of Y Est	0.001864
R Squared	0.999956
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.728124
Std Err of Coef.	0.001536

Regression Output: N15 ^ 0.985=a+b*Vx

Constant	−0.0097
Std Err of Y Est	0.002561
R Squared	0.999956
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.373331
Std Err of Coef.	0.002897

Meter P–1
For 30 Degrees Left of Vertical Plane

Vx = Vs*Cos 30 (m/s)	N30	N ^ 0.994	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0433	0.055	0.055	0.0436	0.70
0.0866	0.118	0.120	0.0860	−0.72
0.1299	0.185	0.186	0.1302	0.23
0.1732	0.250	0.252	0.1737	0.27
0.2165	0.318	0.320	0.2184	0.87
0.2598	0.381	0.383	0.2604	0.23
0.3031	0.445	0.447	0.3024	−0.24
0.3464	0.508	0.510	0.3443	−0.60
0.3897	0.576	0.578	0.3892	−0.13
0.4330	0.640	0.642	0.4314	−0.37
0.6495	0.975	0.975	0.6520	0.38
0.8660	1.300	1.298	0.8655	−0.06

Regression Output: Vx=a+b*N30 ^ 0.994

Constant	0.006916
Std Err of Y Est	0.001367
R Squared	0.99997
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.66151
Std Err of Coef.	0.001141

Regression Output: N30 ^ 0.994=a+b*Vx

Constant	−0.01044
Std Err of Y Est	0.002067
R Squared	0.99997
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.511648
Std Err of Coef.	0.002608

Meter P–1
For 10 Degrees Right of Vertical Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 0.964	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.058			
0.0985	0.132	0.142	0.0979	−0.57
0.1477	0.200	0.211	0.1498	1.37
0.1970	0.264	0.277	0.1987	0.87
0.2462	0.330	0.343	0.2483	0.85
0.2954	0.396	0.409	0.2975	0.71
0.3447	0.459	0.472	0.3439	−0.22
0.3939	0.524	0.536	0.3923	−0.42
0.4432	0.590	0.601	0.4404	−0.62
0.4924	0.655	0.665	0.4883	−0.83
0.7386	0.998	0.998	0.7365	−0.28
0.9848	1.350	1.335	0.9888	0.40

Regression Output:	Vx=a+b*N10 ^ 0.964
Constant	−0.00805
Std Err of Y Est	0.002655
R Squared	0.999909
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.746398
Std Err of Coef.	0.002368

Regression Output:	N10 ^ 0.964=a+b*Vx
Constant	0.010837
Std Err of Y Est	0.003557
R Squared	0.999909
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.339647
Std Err of Coef.	0.00425

Meter P–1
For 15 Degrees Right of Vertical Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 0.980	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483	0.057			
0.0966	0.125	0.130	0.0965	−0.05
0.1449	0.191	0.197	0.1452	0.19
0.1932	0.256	0.263	0.1934	0.13
0.2415	0.323	0.330	0.2422	0.29
0.2898	0.387	0.394	0.2893	−0.17
0.3381	0.455	0.462	0.3388	0.20
0.3864	0.520	0.527	0.3859	−0.12
0.4347	0.585	0.591	0.4330	−0.39
0.4830	0.655	0.661	0.4835	0.11
0.7244	0.990	0.990	0.7241	−0.05
0.9659	1.330	1.322	0.9665	0.06

Regression Output: Vx=a+b*N15 ^ 0.980

Constant	0.001455
Std Err of Y Est	0.000763
R Squared	0.999992
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.729764
Std Err of Coef.	0.000678

Regression Output: N15 ^ 0.980=a+b*Vx

Constant	−0.00199
Std Err of Y Est	0.001046
R Squared	0.999992
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.370295
Std Err of Coef.	0.001274

Meter P–1
For 30 Degrees Right of Vertical Plane

Vx = Vs*Cos 30 (m/s)	N30	N ^ 0.992	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0433	0.058	0.059	0.0433	–0.03
0.0866	0.120	0.122	0.0862	–0.45
0.1299	0.183	0.186	0.1293	–0.47
0.1732	0.246	0.249	0.1723	–0.55
0.2165	0.310	0.313	0.2158	–0.32
0.2598	0.375	0.378	0.2600	0.06
0.3031	0.438	0.440	0.3024	–0.24
0.3464	0.504	0.507	0.3474	0.29
0.3897	0.567	0.570	0.3901	0.09
0.4330	0.635	0.637	0.4361	0.71
0.6495	0.953	0.953	0.6503	0.12
0.8660	1.270	1.268	0.8640	–0.23

Regression Output:		Vx=a+b*N30 ^ 0.992
Constant		0.003345
Std Err of Y Est		0.001331
R Squared		0.999972
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.678985	
Std Err of Coef.	0.00114	

Regression Output:		N30 ^ 0.992=a+b*Vx
Constant		–0.00491
Std Err of Y Est		0.00196
R Squared		0.999972
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.472746	
Std Err of Coef.	0.002473	

Meter P–3
For 10 Degrees Left of Vertical Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 0.965	Vx using model; Vmod	(Vmod–Vx)/Vx (%)
0.0492	0.061			
0.0985	0.124	0.133	0.0986	0.14
0.1477	0.189	0.200	0.1490	0.86
0.1970	0.252	0.264	0.1972	0.13
0.2462	0.315	0.328	0.2450	−0.48
0.2954	0.381	0.394	0.2947	−0.24
0.3447	0.445	0.457	0.3423	−0.70
0.3939	0.512	0.524	0.3926	−0.34
0.4432	0.581	0.592	0.4434	0.04
0.4924	0.650	0.660	0.4947	0.46
0.7386	0.990	0.990	0.7433	0.63
0.9848	1.320	1.307	0.9817	−0.32

Regression Output:	Vx=a+b*N10 ^ 0.965
Constant	−0.00173
Std Err of Y Est	0.002313
R Squared	0.999931
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.752276
Std Err of Coef.	0.002079

Regression Output:	N10 ^ 0.965=a+b*Vx
Constant	0.002337
Std Err of Y Est	0.003074
R Squared	0.999931
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.329209
Std Err of Coef.	0.003673

Meter P–3
For 15 Degrees Left of Vertical Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 0.964	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483	0.061			
0.0966	0.124	0.134	0.0966	−0.00
0.1449	0.189	0.201	0.1461	0.81
0.1932	0.252	0.265	0.1934	0.11
0.2415	0.315	0.328	0.2403	−0.48
0.2898	0.381	0.394	0.2891	−0.23
0.3381	0.445	0.458	0.3358	−0.68
0.3864	0.512	0.524	0.3851	−0.33
0.4347	0.581	0.592	0.4349	0.06
0.4830	0.650	0.660	0.4853	0.48
0.7244	0.990	0.990	0.7291	0.64
0.9659	1.320	1.307	0.9627	−0.33

Regression Output: Vx=a+b*N15 ^ 0.964

Constant	−0.0021
Std Err of Y Est	0.002283
R Squared	0.99993
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.738271
Std Err of Coef.	0.002053

Regression Output: N15 ^ 0.964=a+b*Vx

Constant	0.002883
Std Err of Y Est	0.003092
R Squared	0.99993
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.354422
Std Err of Coef.	0.003767

Meter P–3
For 30 Degrees Left of Vertical Plane

Vx = Vs*Cos 30 (m/s)	N30	N ^ 1.004	Vx using model; Vmod	(Vmod–Vx)/Vx (%)
0.0433	0.061	0.060	0.0437	0.84
0.0866	0.125	0.124	0.0858	–0.93
0.1299	0.192	0.191	0.1297	–0.19
0.1732	0.260	0.259	0.1742	0.59
0.2165	0.325	0.324	0.2169	0.17
0.2598	0.390	0.389	0.2596	–0.09
0.3031	0.455	0.454	0.3023	–0.27
0.3464	0.520	0.519	0.3450	–0.40
0.3897	0.590	0.588	0.3908	0.27
0.4330	0.655	0.654	0.4339	0.20
0.6495	0.983	0.982	0.6497	0.02
0.8660	1.310	1.311	0.8657	–0.03

Regression Output:		Vx=a+b*N30 ^ 1.004
Constant		0.004373
Std Err of Y Est		0.000812
R Squared		0.99999
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.656824	
Std Err of Coef.	0.000673	

Regression Output:		N30 ^ 1.004=a+b*Vx
Constant		–0.00665
Std Err of Y Est		0.001236
R Squared		0.99999
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.522461	
Std Err of Coef.	0.001559	

Meter P–3
For 10 Degrees Right of Vertical Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 0.990	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.060	0.062	0.0492	−0.06
0.0985	0.127	0.130	0.0988	0.29
0.1477	0.194	0.197	0.1477	−0.02
0.1970	0.260	0.264	0.1964	−0.27
0.2462	0.330	0.334	0.2476	0.57
0.2954	0.396	0.400	0.2958	0.11
0.3447	0.462	0.466	0.3438	−0.25
0.3939	0.532	0.535	0.3947	0.21
0.4432	0.599	0.602	0.4430	−0.03
0.4924	0.665	0.668	0.4913	−0.23
0.7386	1.005	1.005	0.7373	−0.18
0.9848	1.350	1.346	0.9860	0.12

Regression Output:		Vx=a+b*N10 ^ 0.990
Constant		0.004195
Std Err of Y Est		0.000915
R Squared		0.99999
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.729475	
Std Err of Coef.	0.000741	

Regression Output:		N10 ^ 0.990=a+b*Vx
Constant		−0.00575
Std Err of Y Est		0.001254
R Squared		0.99999
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.370834	
Std Err of Coef.	0.001392	

Meter P–3
For 15 Degrees Right of Vertical Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 0.997	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483	0.058	0.058	0.0484	0.28
0.0966	0.125	0.126	0.0967	0.13
0.1449	0.194	0.194	0.1456	0.51
0.1932	0.260	0.261	0.1931	–0.06
0.2415	0.330	0.331	0.2430	0.61
0.2898	0.396	0.397	0.2900	0.07
0.3381	0.462	0.463	0.3370	–0.33
0.3864	0.532	0.533	0.3868	0.10
0.4347	0.599	0.599	0.4341	–0.14
0.4830	0.665	0.666	0.4814	–0.33
0.7244	1.005	1.005	0.7229	–0.21
0.9659	1.350	1.349	0.9678	0.20

Regression Output: Vx=a+b*N15 ^ 0.997

Constant	0.007125
Std Err of Y Est	0.001139
R Squared	0.999983
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.712265
Std Err of Coef.	0.000918

Regression Output: N15 ^ 0.997=a+b*Vx

Constant	–0.01
Std Err of Y Est	0.001599
R Squared	0.999983
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.403948
Std Err of Coef.	0.001809

Meter P–3
For 30 Degrees Right of Vertical Plane

Vx = Vs*Cos 30 (m/s)	N30	N ^ 1.021	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0433	0.060	0.056	0.0433	−0.05
0.0866	0.127	0.122	0.0859	−0.82
0.1299	0.195	0.188	0.1293	−0.44
0.1732	0.260	0.253	0.1712	−1.18
0.2165	0.330	0.322	0.2164	−0.03
0.2598	0.396	0.388	0.2593	−0.18
0.3031	0.462	0.455	0.3024	−0.24
0.3464	0.532	0.525	0.3482	0.51
0.3897	0.599	0.592	0.3918	0.53
0.4330	0.665	0.659	0.4355	0.58
0.6495	0.990	0.990	0.6504	0.13
0.8660	1.310	1.317	0.8634	−0.30

Regression Output: Vx=a+b*N30 ^ 1.021

Constant	0.006817
Std Err of Y Est	0.001643
R Squared	0.999957
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.65021
Std Err of Coef.	0.001348

Regression Output: N30 ^ 1.021 = a+b*Vx

Constant	−0.01046
Std Err of Y Est	0.002526
R Squared	0.999957
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.537898
Std Err of Coef.	0.003187

Meter P–4
For 10 Degrees Left of Vertical Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 1.010	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.056	0.054	0.0493	0.07
0.0985	0.125	0.122	0.0982	−0.26
0.1477	0.194	0.190	0.1468	−0.65
0.1970	0.262	0.259	0.1955	−0.76
0.2462	0.333	0.329	0.2457	−0.19
0.2954	0.402	0.398	0.2954	−0.01
0.3447	0.473	0.469	0.3459	0.34
0.3939	0.540	0.537	0.3943	0.08
0.4432	0.612	0.609	0.4459	0.62
0.4924	0.680	0.677	0.4948	0.48
0.7386	1.013	1.013	0.7344	−0.58
0.9848	1.360	1.364	0.9856	0.08

Regression Output: Vx=a+b*N10 ^ 1.010

Constant	0.010743
Std Err of Y Est	0.001922
R Squared	0.999955
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.714587
Std Err of Coef.	0.001524

Regression Output: N10 ^ 1.010=a+b*Vx

Constant	−0.01501
Std Err of Y Est	0.002689
R Squared	0.999955
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.399346
Std Err of Coef.	0.002984

Meter P–4
For 15 Degrees Left of Vertical Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.010	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483	0.056	0.054	0.0483	0.07
0.0966	0.125	0.122	0.0963	−0.26
0.1449	0.194	0.190	0.1439	−0.65
0.1932	0.262	0.259	0.1917	−0.76
0.2415	0.333	0.329	0.2410	−0.19
0.2898	0.402	0.398	0.2897	−0.01
0.3381	0.473	0.469	0.3392	0.34
0.3864	0.540	0.537	0.3867	0.08
0.4347	0.612	0.609	0.4374	0.62
0.4830	0.680	0.677	0.4853	0.48
0.7244	1.013	1.013	0.7203	−0.58
0.9659	1.360	1.364	0.9667	0.08

Regression Output:		Vx=a+b*N15 ^ 1.010
Constant		0.010537
Std Err of Y Est		0.001885
R Squared		0.999955
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.700888	
Std Err of Coef.	0.001495	

Regression Output:		N15 ^ 1.010=a+b*Vx
Constant		−0.01501
Std Err of Y Est		0.002689
R Squared		0.999955
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.426697	
Std Err of Coef.	0.003042	

Meter P–4
For 30 Degrees Left of Vertical Plane

Vx = Vs*Cos 30 (m/s)	N30	N ^ 1.006	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0433	0.060	0.059	0.0436	0.77
0.0866	0.127	0.125	0.0859	–0.82
0.1299	0.195	0.193	0.1286	–1.00
0.1732	0.266	0.264	0.1733	0.06
0.2165	0.335	0.333	0.2168	0.14
0.2598	0.402	0.400	0.2591	–0.27
0.3031	0.473	0.470	0.3037	0.18
0.3464	0.540	0.538	0.3464	–0.02
0.3897	0.612	0.610	0.3919	0.57
0.4330	0.680	0.678	0.4350	0.46
0.6495	1.013	1.013	0.6460	–0.55
0.8660	1.360	1.363	0.8669	0.10

Regression Output: Vx=a+b*N30 ^ 1.006

Constant	0.006701
Std Err of Y Est	0.001597
R Squared	0.999959
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.631317
Std Err of Coef.	0.001272

Regression Output: N30 ^ 1.006=a+b*Vx

Constant	–0.01059
Std Err of Y Est	0.00253
R Squared	0.999959
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.583926
Std Err of Coef.	0.003192

Meter P–4
For 10 Degrees Right of Vertical Plane

Vx = Vs*Cos 10 (m/s)	N10	N ^ 0.998	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0492	0.063	0.063	0.0489	−0.70
0.0985	0.133	0.134	0.0991	0.67
0.1477	0.201	0.202	0.1479	0.11
0.1970	0.268	0.269	0.1959	−0.55
0.2462	0.338	0.338	0.2457	−0.22
0.2954	0.405	0.406	0.2940	−0.50
0.3447	0.476	0.477	0.3448	0.03
0.3939	0.544	0.545	0.3934	−0.13
0.4432	0.617	0.617	0.4453	0.47
0.4924	0.685	0.686	0.4942	0.37
0.7386	1.028	1.027	0.7390	0.05
0.9848	1.370	1.369	0.9836	−0.13

Regression Output:		Vx=a+b*N10 ^ 0.998
Constant		0.003554
Std Err of Y Est		0.00118
R Squared		0.999983
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	0.71578	
Std Err of Coef.	0.000937	

Regression Output:		N10 ^ 0.998=a+b*Vx
Constant		−0.00496
Std Err of Y Est		0.001648
R Squared		0.999983
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	1.397053	
Std Err of Coef.	0.001829	

Meter P–4
For 15 Degrees Right of Vertical Plane

Vx = Vs*Cos 15 (m/s)	N15	N ^ 1.015	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0483	0.063	0.060	0.0485	0.45
0.0966	0.133	0.129	0.0969	0.34
0.1449	0.201	0.196	0.1443	−0.38
0.1932	0.268	0.263	0.1913	−0.98
0.2415	0.338	0.332	0.2402	−0.53
0.2898	0.405	0.400	0.2878	−0.67
0.3381	0.476	0.471	0.3381	−0.00
0.3864	0.544	0.539	0.3863	−0.02
0.4347	0.617	0.612	0.4378	0.72
0.4830	0.685	0.681	0.4866	0.74
0.7244	1.020	1.020	0.7259	0.21
0.9659	1.350	1.356	0.9629	−0.31

Regression Output: Vx=a+b*N15 ^ 1.015

Constant	0.005857
Std Err of Y Est	0.002086
R Squared	0.999944
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.705748
Std Err of Coef.	0.001665

Regression Output: N15 ^ 1.015=a+b*Vx

Constant	−0.00827
Std Err of Y Est	0.002955
R Squared	0.999944
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.416858
Std Err of Coef.	0.003343

Meter P–4
For 30 Degrees Right of Vertical Plane

Vx = Vs*Cos 30 (m/s)	N30	N ^ 1.019	Vx using model; Vmod	Vmod–Vx / Vx (%)
0.0433	0.058	0.054	0.0431	−0.56
0.0866	0.128	0.123	0.0872	0.64
0.1299	0.197	0.191	0.1305	0.44
0.1732	0.264	0.257	0.1734	0.14
0.2165	0.333	0.326	0.2173	0.35
0.2598	0.399	0.392	0.2600	0.07
0.3031	0.466	0.459	0.3028	−0.09
0.3464	0.532	0.526	0.3458	−0.18
0.3897	0.599	0.593	0.3889	−0.22
0.4330	0.665	0.660	0.4320	−0.23
0.6495	0.998	0.997	0.6489	−0.09
0.8660	1.330	1.337	0.8672	0.14

Regression Output: Vx=a+b*N30 ^ 1.019

Constant	0.008064
Std Err of Y Est	0.000728
R Squared	0.999992
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.64251
Std Err of Coef.	0.00059

Regression Output: N30 ^ 1.019=a+b*Vx

Constant	−0.01255
Std Err of Y Est	0.001133
R Squared	0.999992
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	1.556382
Std Err of Coef.	0.001429

Appendix D - Performance data for placement normal to flow

Computed Revolutions/Metre
For Meters Parallel to Flow

Vs (m/s)	P-1 N0/Vs (rev/m)	P-3 N0/Vs (rev/m)	P-4 N0/Vs (rev/m)	1-179 N0/Vs (rev/m)
0.05	1.12	1.13	1.25	1.32
0.10	1.18	1.25	1.31	1.38
0.15	1.23	1.28	1.35	1.41
0.20	1.26	1.30	1.35	1.43
0.25	1.28	1.30	1.36	1.44
0.30	1.30	1.31	1.36	1.45
0.35	1.32	1.32	1.36	1.46
0.40	1.33	1.32	1.36	1.47
0.45	1.34	1.33	1.37	1.48
0.50	1.35	1.33	1.37	1.48
0.60	1.35	1.33	1.37	1.49
0.80	1.35	1.34	1.37	1.50
1.00	1.35	1.34	1.37	1.50

Appendix E - Relative errors for placement with vertical departure

Meter 1–179
Errors for Angles Below
Horizontal Plane

Vx m/s	N5 rev/s	N10 rev/s	N15 rev/s	Vx5	Vx10	Vx15	RE (%) $\frac{Vx5 - Vx}{Vx}$	$\frac{Vx10 - Vx}{Vx}$	$\frac{Vx15 - Vx}{Vx}$
0.10	0.134	0.139	0.138	0.099	0.102	0.101	−1.47	1.87	1.20
0.25	0.356	0.364	0.367	0.246	0.251	0.252	−1.75	0.40	0.97
0.50	0.728	0.739	0.747	0.492	0.500	0.504	−1.56	−0.10	0.89
0.75	1.102	1.114	1.127	0.740	0.748	0.756	−1.38	−0.26	0.86
1.00	1.476	1.489	1.507	0.988	0.997	1.008	−1.22	−0.34	0.85

Meter 1–179
Errors for Angles Above
Horizontal Plane

Vx m/s	N5 rev/s	N10 rev/s	N15 rev/s	Vx5	Vx10	Vx15	RE (%) $\frac{Vx5 - Vx}{Vx}$	$\frac{Vx10 - Vx}{Vx}$	$\frac{Vx15 - Vx}{Vx}$
0.10	0.132	0.129	0.136	0.097	0.095	0.099	−2.89	−4.80	−0.66
0.25	0.354	0.344	0.326	0.244	0.237	0.225	−2.48	−5.12	−9.88
0.50	0.724	0.701	0.659	0.489	0.474	0.446	−2.14	−5.22	−10.80
0.75	1.095	1.058	1.003	0.735	0.711	0.675	−1.94	−5.26	−10.06
1.00	1.467	1.415	1.356	0.982	0.947	0.908	−1.80	−5.28	−9.16

Meter P–1
Errors for Angles Below
Horizontal Plane

Vx m/s	N5 rev/s	N10 rev/s	N15 rev/s	Vx5	Vx10	Vx15	RE (%) Vx5 – Vx / Vx	Vx10 – Vx / Vx	Vx15 – Vx / Vx
0.10	0.124	0.113	0.112	0.106	0.097	0.096	5.67	−2.72	−3.67
0.25	0.323	0.305	0.289	0.250	0.237	0.225	−0.12	−5.34	−10.04
0.50	0.655	0.624	0.584	0.491	0.468	0.439	−1.90	−6.41	−12.23
0.75	0.987	0.941	0.878	0.732	0.699	0.653	−2.42	−6.84	−12.99
1.00	1.318	1.257	1.171	0.973	0.929	0.866	−2.65	−7.10	−13.38

Meter P–1
Errors for Angles Above
Horizontal Plane

Vx m/s	N5 rev/s	N10 rev/s	N15 rev/s	Vx5	Vx10	Vx15	RE (%) Vx5 – Vx / Vx	Vx10 – Vx / Vx	Vx15 – Vx / Vx
0.10	0.118	0.108	0.100	0.101	0.094	0.088	0.88	−6.07	−11.84
0.25	0.317	0.299	0.277	0.245	0.232	0.216	−2.03	−7.06	−13.71
0.50	0.645	0.616	0.563	0.483	0.462	0.424	−3.31	−7.58	−15.20
0.75	0.972	0.931	0.846	0.721	0.691	0.630	−3.87	−7.84	−16.06
1.00	1.297	1.245	1.126	0.958	0.920	0.833	−4.21	−8.00	−16.67

Meter P–3
Errors for Angles Below
Horizontal Plane

Vx m/s	N5 rev/s	N10 rev/s	N15 rev/s	Vx5	Vx10	Vx15	RE (%) Vx5 – Vx / Vx	Vx10 – Vx / Vx	Vx15 – Vx / Vx
0.10	0.127	0.121	0.114	0.102	0.098	0.092	2.26	−1.99	−7.72
0.25	0.330	0.319	0.306	0.252	0.244	0.235	0.99	−2.39	−6.03
0.50	0.669	0.647	0.621	0.503	0.486	0.468	0.57	−2.71	−6.42
0.75	1.007	0.973	0.932	0.753	0.728	0.698	0.43	−2.91	−6.96
1.00	1.346	1.300	1.241	1.004	0.970	0.926	0.36	−3.04	−7.42

Meter P–3
Errors for Angles Above
Horizontal Plane

Vx m/s	N5 rev/s	N10 rev/s	N15 rev/s	Vx5	Vx10	Vx15	RE (%) Vx5 – Vx / Vx	Vx10 – Vx / Vx	Vx15 – Vx / Vx
0.10	0.122	0.113	0.095	0.098	0.092	0.079	−1.70	−8.18	−21.13
0.25	0.320	0.309	0.288	0.245	0.237	0.221	−2.08	−5.35	−11.51
0.50	0.654	0.631	0.599	0.492	0.475	0.451	−1.62	−5.00	−9.71
0.75	0.991	0.951	0.905	0.741	0.712	0.677	−1.19	−5.13	−9.69
1.00	1.329	1.269	1.207	0.991	0.947	0.901	−0.85	−5.32	−9.94

Meter P–4
Errors for Angles Below
Horizontal Plane

Vx m/s	N5 rev/s	N10 rev/s	N15 rev/s	Vx5	Vx10	Vx15	RE (%) $\frac{Vx5 - Vx}{Vx}$	RE (%) $\frac{Vx10 - Vx}{Vx}$	RE (%) $\frac{Vx15 - Vx}{Vx}$
0.10	0.131	0.129	0.122	0.100	0.098	0.093	−0.33	−1.96	−7.16
0.25	0.342	0.341	0.323	0.252	0.251	0.238	0.70	0.36	−4.74
0.50	0.684	0.684	0.650	0.500	0.500	0.476	−0.02	0.05	−4.90
0.75	1.020	1.022	0.972	0.745	0.746	0.710	−0.72	−0.52	−5.36
1.00	1.353	1.356	1.291	0.987	0.990	0.942	−1.29	−1.02	−5.79

Meter P–4
Errors for Angles Above
Horizontal Plane

Vx m/s	N5 rev/s	N10 rev/s	N15 rev/s	Vx5	Vx10	Vx15	RE (%) $\frac{Vx5 - Vx}{Vx}$	RE (%) $\frac{Vx10 - Vx}{Vx}$	RE (%) $\frac{Vx15 - Vx}{Vx}$
0.10	0.124	0.114	0.112	0.094	0.087	0.086	−5.76	−12.92	−14.39
0.25	0.330	0.317	0.303	0.243	0.234	0.224	−2.71	−6.43	−10.46
0.50	0.675	0.649	0.619	0.494	0.474	0.453	−1.25	−5.12	−9.42
0.75	1.021	0.976	0.933	0.746	0.712	0.681	−0.57	−5.03	−9.19
1.00	1.369	1.300	1.245	0.999	0.948	0.909	−0.13	−5.16	−9.12

Appendix F - Relative errors for placement with horizontal departure

Meter 1–179, 1–061
Errors for Angles Left
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) Vx10 – Vx / Vx	Vx15 – Vx / Vx	Vx30 – Vx / Vx
0.10	0.128	0.142	0.154	0.094	0.104	0.112	−5.77	3.74	11.78
0.25	0.360	0.370	0.403	0.249	0.255	0.277	−0.32	1.87	10.65
0.50	0.741	0.748	0.818	0.505	0.505	0.552	0.94	1.05	10.32
0.75	1.119	1.125	1.233	0.758	0.755	0.827	1.12	0.69	10.23
1.00	1.494	1.501	1.648	1.011	1.005	1.102	1.10	0.46	10.19

Meter 1–179, 1–061
Errors for Angles Right
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) Vx10 – Vx / Vx	Vx15 – Vx / Vx	Vx30 – Vx / Vx
0.10	0.137	0.140	0.149	0.100	0.102	0.108	0.10	2.24	8.29
0.25	0.371	0.373	0.390	0.257	0.257	0.268	2.75	2.65	7.10
0.50	0.755	0.760	0.790	0.514	0.513	0.533	2.83	2.58	6.67
0.75	1.134	1.145	1.191	0.769	0.769	0.799	2.51	2.47	6.50
1.00	1.510	1.530	1.591	1.022	1.024	1.064	2.19	2.37	6.41

Meter P–1
Errors for Angles Left
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) Vx10 – Vx / Vx	Vx15 – Vx / Vx	Vx30 – Vx / Vx
0.10	0.124	0.124	0.139	0.105	0.105	0.116	5.44	5.10	16.21
0.25	0.326	0.328	0.365	0.252	0.253	0.280	0.63	1.24	12.02
0.50	0.664	0.673	0.744	0.497	0.504	0.555	−0.62	0.72	11.07
0.75	1.002	1.021	1.124	0.743	0.757	0.832	−0.88	0.89	10.94
1.00	1.342	1.370	1.505	0.991	1.011	1.110	−0.93	1.14	10.98

Meter P–1
Errors for Angles Right
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) Vx10 – Vx / Vx	Vx15 – Vx / Vx	Vx30 – Vx / Vx
0.10	0.135	0.130	0.140	0.113	0.109	0.117	13.07	9.39	16.99
0.25	0.332	0.333	0.360	0.256	0.257	0.276	2.46	2.71	10.59
0.50	0.671	0.678	0.730	0.502	0.507	0.545	0.43	1.43	8.96
0.75	1.016	1.026	1.100	0.753	0.761	0.815	0.46	1.44	8.65
1.00	1.366	1.377	1.472	1.008	1.017	1.086	0.83	1.65	8.61

Meter P–3
Errors for Angles Left
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) $\frac{Vx10 - Vx}{Vx}$	$\frac{Vx15 - Vx}{Vx}$	$\frac{Vx30 - Vx}{Vx}$
0.10	0.126	0.128	0.147	0.101	0.103	0.117	1.35	3.34	16.83
0.25	0.322	0.328	0.375	0.246	0.251	0.286	−1.53	0.37	14.39
0.50	0.657	0.670	0.755	0.494	0.504	0.567	−1.13	0.81	13.39
0.75	0.999	1.019	1.135	0.747	0.762	0.847	−0.37	1.62	12.99
1.00	1.345	1.373	1.513	1.003	1.024	1.127	0.33	2.36	12.74

Meter P–3
Errors for Angles Right
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) $\frac{Vx10 - Vx}{Vx}$	$\frac{Vx15 - Vx}{Vx}$	$\frac{Vx30 - Vx}{Vx}$
0.10	0.129	0.130	0.149	0.103	0.104	0.119	3.48	4.17	18.64
0.25	0.333	0.340	0.382	0.255	0.260	0.291	1.92	3.87	16.23
0.50	0.677	0.691	0.763	0.509	0.519	0.572	1.80	3.90	14.49
0.75	1.023	1.043	1.140	0.765	0.780	0.851	1.94	3.96	13.50
1.00	1.369	1.395	1.514	1.021	1.040	1.128	2.10	4.02	12.81

Meter P–4
Errors for Angles Left
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) Vx10 – Vx / Vx	Vx15 – Vx / Vx	Vx30 – Vx / Vx
0.10	0.128	0.130	0.149	0.097	0.099	0.113	−3.11	−1.12	12.74
0.25	0.338	0.345	0.388	0.249	0.254	0.285	−0.25	1.74	13.99
0.50	0.687	0.701	0.783	0.503	0.512	0.572	0.50	2.48	14.36
0.75	1.034	1.054	1.176	0.755	0.770	0.858	0.66	2.63	14.46
1.00	1.380	1.407	1.569	1.007	1.027	1.145	0.70	2.67	14.51

Meter P–4
Errors for Angles Right
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) Vx10 – Vx / Vx	Vx15 – Vx / Vx	Vx30 – Vx / Vx
0.10	0.134	0.137	0.148	0.102	0.104	0.112	1.71	4.04	11.92
0.25	0.344	0.351	0.383	0.253	0.259	0.282	1.23	3.50	12.79
0.50	0.693	0.704	0.769	0.507	0.515	0.562	1.35	2.92	12.46
0.75	1.043	1.054	1.152	0.761	0.769	0.841	1.51	2.55	12.08
1.00	1.393	1.401	1.531	1.017	1.023	1.118	1.66	2.27	11.75

Appendix G - Relative errors for placement with horizontal departures when cosine corrections are applied

Meter 1–179, 1–061
Errors for Angles Left
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) (Vx10* Cos10)–Vx / Vx	RE (%) (Vx15* Cos15)–Vx / Vx	RE (%) (Vx30* Cos30)–Vx / Vx
0.10	0.128	0.142	0.154	0.094	0.104	0.112	−7.20	0.20	−3.19
0.25	0.360	0.370	0.403	0.249	0.255	0.277	−1.83	−1.60	−4.17
0.50	0.741	0.748	0.818	0.505	0.505	0.552	−0.59	−2.40	−4.46
0.75	1.119	1.125	1.233	0.758	0.755	0.827	−0.41	−2.75	−4.54
1.00	1.494	1.501	1.648	1.011	1.005	1.102	−0.44	−2.96	−4.57

Meter 1–179, 1–061
Errors for Angles Right
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) (Vx10* Cos10)–Vx / Vx	RE (%) (Vx15* Cos15)–Vx / Vx	RE (%) (Vx30* Cos30)–Vx / Vx
0.10	0.137	0.140	0.149	0.100	0.102	0.108	−1.42	−1.24	−6.22
0.25	0.371	0.373	0.390	0.257	0.257	0.268	1.19	−0.84	−7.25
0.50	0.755	0.760	0.790	0.514	0.513	0.533	1.26	−0.91	−7.62
0.75	1.134	1.145	1.191	0.769	0.769	0.799	0.95	−1.02	−7.77
1.00	1.510	1.530	1.591	1.022	1.024	1.064	0.63	−1.12	−7.85

Meter P–1
Errors for Angles Left
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) (Vx10* Cos10) – Vx / Vx	RE (%) (Vx15* Cos15) – Vx / Vx	RE (%) (Vx30* Cos30) – Vx / Vx
0.10	0.124	0.124	0.139	0.105	0.105	0.116	3.84	1.52	0.64
0.25	0.326	0.328	0.365	0.252	0.253	0.280	−0.90	−2.21	−2.99
0.50	0.664	0.673	0.744	0.497	0.504	0.555	−2.13	−2.71	−3.81
0.75	1.002	1.021	1.124	0.743	0.757	0.832	−2.39	−2.55	−3.92
1.00	1.342	1.370	1.505	0.991	1.011	1.110	−2.44	−2.30	−3.89

Meter P–1
Errors for Angles Right
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) (Vx10* Cos10) – Vx / Vx	RE (%) (Vx15* Cos15) – Vx / Vx	RE (%) (Vx30* Cos30) – Vx / Vx
0.10	0.135	0.130	0.140	0.113	0.109	0.117	11.35	5.67	1.32
0.25	0.332	0.333	0.360	0.256	0.257	0.276	0.90	−0.79	−4.23
0.50	0.671	0.678	0.730	0.502	0.507	0.545	−1.10	−2.02	−5.63
0.75	1.016	1.026	1.100	0.753	0.761	0.815	−1.07	−2.02	−5.91
1.00	1.366	1.377	1.472	1.008	1.017	1.086	−0.71	−1.81	−5.94

Meter P–3
Errors for Angles Left
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) (Vx10* Cos10) – Vx / Vx	RE (%) (Vx15* Cos15) – Vx / Vx	RE (%) (Vx30* Cos30) – Vx / Vx
0.10	0.126	0.128	0.147	0.101	0.103	0.117	−0.19	−0.18	1.18
0.25	0.322	0.328	0.375	0.246	0.251	0.286	−3.03	−3.05	−0.94
0.50	0.657	0.670	0.755	0.494	0.504	0.567	−2.63	−2.62	−1.80
0.75	0.999	1.019	1.135	0.747	0.762	0.847	−1.88	−1.84	−2.15
1.00	1.345	1.373	1.513	1.003	1.024	1.127	−1.19	−1.13	−2.36

Meter P–3
Errors for Angles Right
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) (Vx10* Cos10) – Vx / Vx	RE (%) (Vx15* Cos15) – Vx / Vx	RE (%) (Vx30* Cos30) – Vx / Vx
0.10	0.129	0.130	0.149	0.103	0.104	0.119	1.91	0.62	2.75
0.25	0.333	0.340	0.382	0.255	0.260	0.291	0.37	0.33	0.66
0.50	0.677	0.691	0.763	0.509	0.519	0.572	0.25	0.36	−0.85
0.75	1.023	1.043	1.140	0.765	0.780	0.851	0.39	0.42	−1.71
1.00	1.369	1.395	1.514	1.021	1.040	1.128	0.55	0.48	−2.30

Meter P–4
Errors for Angles Left
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) (Vx10* Cos10) – Vx / Vx	RE (%) (Vx15* Cos15) – Vx / Vx	RE (%) (Vx30* Cos30) – Vx / Vx
0.10	0.128	0.130	0.149	0.097	0.099	0.113	−4.58	−4.49	−2.37
0.25	0.338	0.345	0.388	0.249	0.254	0.285	−1.76	−1.73	−1.28
0.50	0.687	0.701	0.783	0.503	0.512	0.572	−1.02	−1.01	−0.96
0.75	1.034	1.054	1.176	0.755	0.770	0.858	−0.87	−0.86	−0.87
1.00	1.380	1.407	1.569	1.007	1.027	1.145	−0.83	−0.83	−0.83

Meter P–4
Errors for Angles Right
of Vertical Plane

Vx m/s	N10 rev/s	N15 rev/s	N30 rev/s	Vx10	Vx15	Vx30	RE (%) (Vx10* Cos10) – Vx / Vx	RE (%) (Vx15* Cos15) – Vx / Vx	RE (%) (Vx30* Cos30) – Vx / Vx
0.10	0.134	0.137	0.148	0.102	0.104	0.112	0.16	0.50	−3.07
0.25	0.344	0.351	0.383	0.253	0.259	0.282	−0.31	−0.02	−2.32
0.50	0.693	0.704	0.769	0.507	0.515	0.562	−0.19	−0.59	−2.61
0.75	1.043	1.054	1.152	0.761	0.769	0.841	−0.03	−0.95	−2.94
1.00	1.393	1.401	1.531	1.017	1.023	1.118	0.11	−1.21	−3.22